...UTE OF TECHNOLOGY OFFICE OF CONTRACT ADMINIS...

PROJECT ADMINISTRATION DATA SHEET

[x] ORIGINAL [ ] REVISION NO. ______

roject No. A-3034 DATE 9/25/81

Project Director: Craig J. Wyvill School/Lab TAL/AED

Sponsor: U.S. Dept. of Interior; Office of Water Research and Technology; Washington, D.C.

Type Agreement: Grant # 14-34-0001-1468

Award Period: From 9/1/81 To 9/30/82 (Performance) 12/1/82 (Reports)

Sponsor Amount: $113,143 Contracted through:

Cost Sharing: $12,565 GTRI/~~GIT~~

Title: An Assessment of the Potential for Water Reuse in the Pulp and Paper Industry

ADMINISTRATIVE DATA OCA Contact Leamon R. Scott

1) Sponsor Technical Contact:

Assistant Director - Research
Office of Water Research & Technology
U. S. Dept. of the Interior
Washington, D.C. 20240

2) Sponsor Admin/Contractual Matters:

Chief, Contracts & Grants Center
Office of Water Research & Technology
U. S. Dept. of the Interior
Washington, D. C. 20240
Attn: F. William Koop

Defense Priority Rating: ______ Security Classification: ______

RESTRICTIONS

See Attached ______ Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval — Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

Equipment: Title vests with None proposed

COMMENTS:

SEP 1981
RECEIVED
Research Reports
Office

COPIES TO:

Administrative Coordinator
Research Property Management
...ion
...Services
Research Security Services
Reports Coordinator (OCA)
Legal Services (OCA)
Library
EES Public Relations (2)
Computer Input
Project File
Other ______

ɔRGIA INSTITUTE OF TECHNOLOGY — OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date 5/29/84

ɔject No. A-3034 — ~~School~~/Lab TAL

ɪcludes Subproject No.(s) ____________________

ʔroject Director(s) Craig J. Wyvill — GTRI / ~~EES~~

Sponsor Department of Interior; Office of Water Research and Technology

Title An Assessment of the Potential for Water Reuse in the Pulp and Paper Industry

Effective Completion Date: 9/30/82 (Performance) 4/15/84 (Reports)

Grant/Contract Closeout Actions Remaining:

- [ ] None
- [x] Final Invoice or Final Fiscal Report
- [ ] Closing Documents
- [x] Final Report of Inventions
- [x] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other ____________________

Continues Project No. ____________________ Continued by Project No. ____________________

COPIES TO:

ʔroject Director
Research Administrative Network
Research Property Management
Accounting
ʔrocurement/EES Supply Services
Research Security Services
Reports Coordinator (OCA)
Legal Services

Library
GTRI
Research Communications (2)
Project File
Other ____________________

An Assessment of the Potential for
Water Reuse in the Pulp and Paper Industry

QUARTERLY PROGRESS REPORT

September - November 1981

Prepared for

The Office of Water Research & Technology
United States Department of the Interior
Under Research Grant #14-34-0001-1468
Starting Date: September 1, 1981

Prepared by

Georgia Institute of Technology
Engineering Experiment Station
Atlanta, Georgia 30332

December 1981

TABLE OF CONTENTS

	Page
INTRODUCTION	1
CHARACTERIZING THE PULP AND PAPER INDUSTRY	1
CHARACTERIZING PULP AND PAPER PROCESSES	5
COMPUTER MODEL ACQUISITION	14
PERSONNEL CHANGES AND FUTURE PLANS	15
APPENDIX A - Computer Operation Exercise Using "GEMS"	17
APPENDIX B - End of Pipe Treatment Technologies Commonly Employed by the Pulp, Paper, and Paperboard Industry	28

LIST OF TABLES

	Page
Table 1 - REGIONAL DISTRIBUTION OF MILLS	2
Table 2 - REGIONAL DISTRIBUTION OF CAPACITY	2
Table 3 - DOMESTIC PAPER AND PAPERBOARD PRODUCTION AND CONSUMPTION FOR 1978	4
Table 4 - WATER USAGE DATA FOR THE PULP AND PAPER INDUSTRY	6
Table 5 - SUMMARY OF EFFLUENT DISCHARGE METHOD AND TREATMENT TECHNOLOGY	7

LIST OF FIGURES

	Page
Figure 1 - DISTRIBUTION OF MILLS BY STATE	3
Figure 2 - DIAGRAM OF ALKALINE PULPING/PAPER PROCESS	9
Figure 3 - DIAGRAM OF SULFITE PULPING/PAPER PROCESS	10
Figure 4 - DIAGRAM OF SEMICHEMICAL/CHEMIMECHANICAL PULPING/PAPER PROCESS	11
Figure 5 - DIAGRAM OF MECHANICAL PULPING/PAPER PROCESS	12
Figure 6 - DIAGRAM OF PAPER FINISHING PROCESS	13

INTRODUCTION

This report highlights the technical progress made from September 1 through November 30 in evaluating the potential for water reuse in the pulp and paper industry. The emphasis thus far has been on gathering and assembling data which can be used to characterize the industry and its production processes. One notable exception has been the acquisition of an operational computer model which allows an assessment of the impact of various water reuse options on production. The study team has successfully acquired the "GEMS" program from Dr. Edwards at the University of Idaho and currently is beginning the transformation of data into a format which should successfully allow it to review alternative water reuse potentials.

CHARACTERIZING THE PULP AND PAPER INDUSTRY

Perhaps the first actions undertaken on the project were those directed at characterizing the industry. Using a host of summary documents acquired through a concentrated literature review, the team was able to assemble information on key aspects of the industry.

To summarize our preliminary findings Tables 1 and 2 show the regional distribution of production mills and their production capacities respectfully. Figure 1 presents the production mill breakdown on a state-by-state basis. Table 3 presents a production and consumption breakdown by production for the domestic pulp and paper industry. Further differentiation of the product categories by geographical region is underway but not available at this time.

Table 1

REGIONAL DISTRIBUTION OF MILLS

Region	Number of Mills	Percent
Northeast	215	34.0
Southeast	144	22.7
North Central	171	27.0
Northwest	41	6.5
West & Southwest	62	9.8
Total	633	100.0

Table 2

REGIONAL DISTRIBUTION OF CAPACITY
(Thousands of short tons/day)

	Pulp**		Paper		Paperboard	
Region*	Capacity	Percent	Capacity	Percent	Capacity	Percent
Northeast	25.83	13.36	23.39	26.73	11.30	10.83
Southeast	94.80	49.05	29.74	33.98	55.77	52.17
North Central	27.62	14.29	19.80	22.62	16.20	15.27
Northwest	23.96	12.40	9.21	10.52	9.06	8.59
West & Southwest	21.06	10.90	5.38	6.15	13.13	13.14
Total	193.27	100.00	85.52	100.00	105.44	100.00

*Northeast includes: Connecticut, Delaware, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, Puerto Rico;

Southeast includes: Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, West Virginia;

North Central includes: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, Wisconsin;

Northwest includes: Alaska, Idaho, Oregon, Washington;

West & Southwest includes: Arizona, California, Colorado, Kansas, Montana, Nevada, New Mexico, Oklahoma, Texas, Utah, Wyoming.

Hawaii -- not in the analysis, but classed in West & Southwest.

**Includes capacity in Deink and Wastepaper (42.08 thousand short tons/day).

Source: "Economic Impact Analysis of Proposed Effluent Limitations Guidelines, New Source Performance Standards and Pretreatment Standards for Pulp and Paper Mills, Vol. 1," U.S. Environmental Protection Agency, December 1980, pages 3-15.

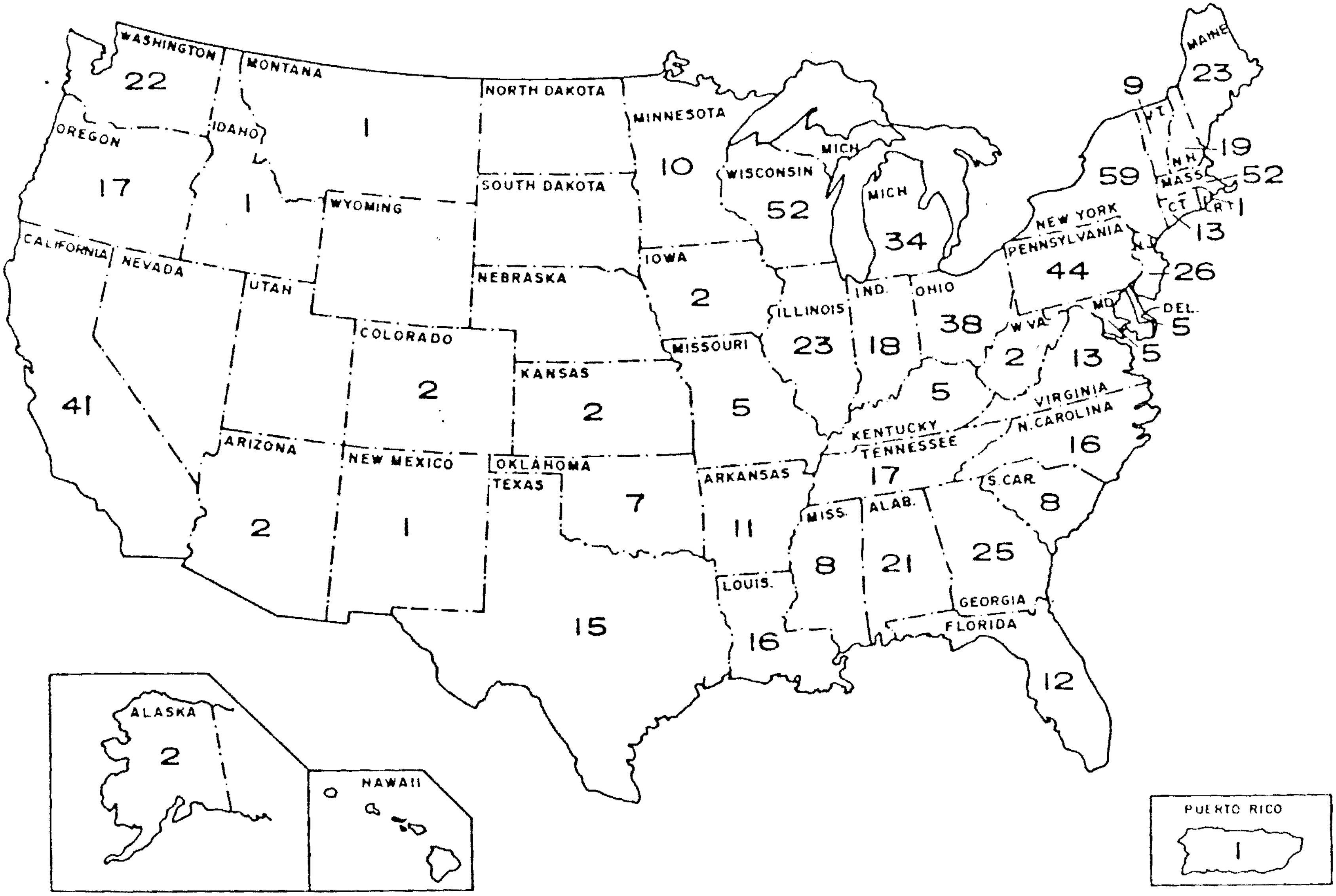


Figure 1. Distribution of Mills by State

Source - "Development Document for Proposed Effluent Limitations Guidelines and Standards for the Pulp, Paper, and Paperboard and the Builders' Paper and Board Mills," U.S. Environmental Protection Agency, December 1980, pg. 69.

Table 3

DOMESTIC PAPER AND PAPERBOARD PRODUCTION AND CONSUMPTION FOR 1978
(in millions of short tons)

	Production	Consumption
Total Paper and Paperboard	64.3	70.4
Paper	28.3	36.2
Newsprint	3.8	11.2
Coated printing, converting	4.4	4.6
Book paper, uncoated, other printing, writing, etc.	10.1	10.6
Packaging and industrial converting	5.8	5.8
Tissue and other mach. creped	4.2	4.2
Paperboard	30.3	27.9
Unbleached Kraft	14.4	12.9
Bleached Kraft	4.0	3.5
Semichemical	4.4	4.4
Recycled finish	7.5	7.5
Construction Paper and Board	5.8	6.2

Source: "Statistical Abstracts of the United States," U.S. Department of the Commerce, 1980, page 738.

Water consumption statistics for the pulp and paper industry are presented in Table 4. These statistics show that roughly 90% of the water currently used in producing pulp and paper products is either recirculated or reused. This reuse statistic results from the economic necessity of recovering expensive compounds in addition to the regional existance of limited water resources and stringent effluent discharge standards. Yet even with this high reuse rate, the industry still withdraws nearly 2 trillion gallons of water annually from surface and undergound sources.

Table 5 presents a summary of current methods the paper industry uses to discharge wastewater and the treatment technologies used in dealing with effluent control. This summary in conjunction with an excellent writeup on the technologies (see Appendix B) is serving as the starting point for further studies into treatment technologies which can further enhance water reuse.

CHARACTERIZING PULP AND PAPER PROCESSES

Members of the study team have been active in defining the major processes and subprocesses that are used by domestic pulp and paper producers. The effort began with a literature search of publications discussing pulp and paper production cycles. This information was then augmented with a review of domestic production facilities in operation (as extracted from the various directories of pulp and paper manufacturers). These two resources allowed the team to catalog current production processes into one of six categories:

Table 4

WATER USAGE DATA FOR THE PULP AND PAPER INDUSTRY
(551 mills reporting)

			(billions of gallons)
Total Water Used			10,400.7
Water Intake			1,963.5
(by source)	public water	276.5	
	surface water	1,222.8	
	ground water	360.3	
	tidewater	77.0	
	other	26.9	
Water Recirculated & Reused			9,216.4
Water Discharge			1,765.1

Source: "1977 Census of Manufacturers," U.S. Department of Commerce, 1979.

TABLE 5

SUMMARY OF EFFLUENT DISCHARGE METHOD AND TREATMENT TECHNOLOGY
All Known Operating Mills

		Method of Discharge							Treatment Scheme - Direct Discharger								
Subcategory	Number of Plants	Direct	Indirect	Indirect Primary	Indirect & Direct	Self-Contained	Unknown	No External Treatment	Primary Only	ASB	ASB w/ Polishing Pond	ASB/w Holding Lagoon	Activated Sludge	Oxidation Pond	Other
Integrated Segment															
Dissolving Kraft	3	3	-	-	-	-	-	-	-	1	1	-	1	-	-
Market Bleached Kraft	12	12	-	-	-	-	-	2	-	1	3	1	4	-	1
BCT Bleached Kraft	9	9	-	-	-	-	-	-	-	4	3	1	-	-	1
Alkaline-Fine[1]	20	16	3	1	-	-	-	-	-	2	3	6	-	1	4
Unbleached Kraft															
Linerboard	20	19	1	-	-	-	-	-	1	3	4	1	2	4	4
Bag	8	8	-	-	-	-	-	-	-	3	2	2	1	-	-
Semi-Chemical	20	18	2	-	-	-	-	1	-	1	8	-	3	-	5
Unbleached Kraft and Semi-Chemical	10	9	1	-	-	-	-	-	-	1	5	2	1	-	1
Dissolving Sulfite Pulp	6	6	-	-	-	-	-	-	1	3	-	-	2	-	2
Papergrade Sulfite[2]	15	12	1	-	2	-	-	-	-	-	-	-	3	-	6
Groundwood-Thermo-Mechanical	4	4	-	-	-	-	-	-	-	2	-	-	2	-	-
Groundwood-CMN Papers	5	2	3	-	-	-	-	-	-	-	-	-	1	-	1
Groundwood-Fine Papers	9	7	2	-	-	-	-	-	-	-	-	-	6	-	1
Integrated Miscellaneous	92	68	13	3	4	2	2	-	6	14	15	3	19	1	10
Secondary Fibers Segment															
Deink															
Fine	5	3	1	1	-	-	-	-	-	-	1	-	2	-	-
Newsprint	6	2	3	-	-	-	1	-	-	2	-	-	-	-	-
Tissue	15	11	2	-	1	1	-	-	3	1	-	1	6	-	-
Tissue from Wastepaper	23	13	3	1	-	6	-	2	4	1	3	1	-	-	2
Paperboard from Wastepaper	159	46	71	20	-	19	3	3	5	9	12	1	7	-	9
Wastepaper Molded Products	18	7	8	1	-	1	1	2	3	1	-	-	-	-	1
Builders' Paper and Roofing Felt	66	10	31	5	-	19	1	-	4	-	2	1	1	1	1
Secondary Fibers - Miscellaneous	22	9	6	3	1	-	3	-	4	1	-	-	3	-	1
Nonintegrated Segment															
Nonintegrated-Fine Papers	45	19	15	4	4	2	1	-	7	4	2	-	2	1	3
Nonintegrated-Tissue Papers	28	14	11	3	-	-	-	1	9	2	-	-	1	1	-
Nonintegrated-Lightweight Papers	18	14	4	-	-	-	-	1	4	1	-	-	-	1	7
Nonintegrated Filter & Nonwoven Papers	14	5	7	2	-	-	-	-	1	-	1	-	1	-	2
Nonintegrated-Paperboard	16	8	8	-	-	-	-	1	4	-	2	-	1	-	-
Nonintegrated Miscellaneous	38	24	6	2	-	4	2	1	15	-	5	-	1	-	2
TOTAL	706	378	202	46	12	54	14	14	71	57	72	20	70	10	64

[1] Includes Fine Bleached Kraft and Soda Subcategories.
[2] Includes Papergrade Sulfite (Blow Pit Wash) and Papergrade Sulfite (Drum Wash) Subcategories.

Source - "Development Document For Proposed Effluent Limitations Guidelines and Standards for The Pulp, Paper, and Paperboard and the Builders' Paper and Board Mills", U.S. Environmental Protection Agency, 1980, p. 70.

- Alkaline (or Kraft) Pulping/Paper Production
- Sulfite Pulping/Paper Production
- Semichemical/Chemimechanical Pulping/Paper Production
- Mechanical Pulping/Paper Production
- Paper Finishing Production
- Other

The category designated "other" is an undesignated one (at present) which has been added to accommodate any mills which might have notable water consumption but does not adequately fit into the other five categories.

Toward the goal of assembling a series of typical subprocess and water flows that makeup each production category, the team has been able to put together Figures 2 through 6. These figures display major subprocess categories consistent with definitions found in the literature and utilized by industry members. For subsequent analyses, select subprocess can periodically be deleted to reflect variations on a production routine (such as eliminating the bleaching stage to represent unbleached Kraft paper production). To the extent that further refinements may be necessary to these diagrams such adjustments will be made as our research continues.

Figures 2 through 6 contain water flow information on the six basic water types know to be commonly used in pulp and paper manufacture. The figures do not show the recirculation and reuse of streams in a process. These flows along with those identified for waste discharge will be overlaid on the figures as the internal operations of each subprocess is further reviewed and assessed.

Refinements to the process flow diagrams and water streams will con-

FIGURE 2

DIAGRAM OF ALKALINE PULPING/PAPER PROCESS
(AND SODIUM BASE SULFITE PULPING)

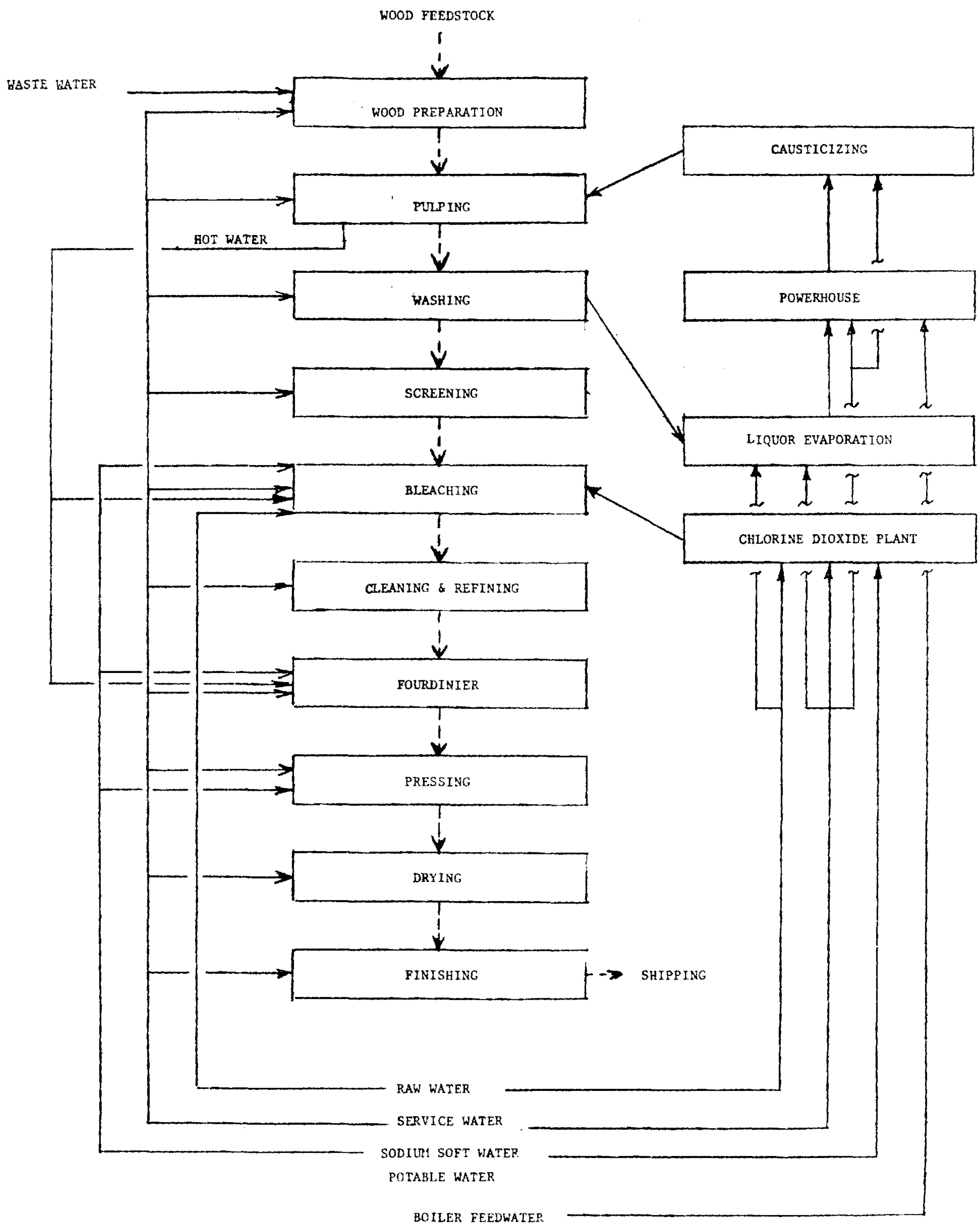


FIGURE 3

DIAGRAM OF SULFITE PULPING/PAPER PROCESS
(CALCIUM BASE)

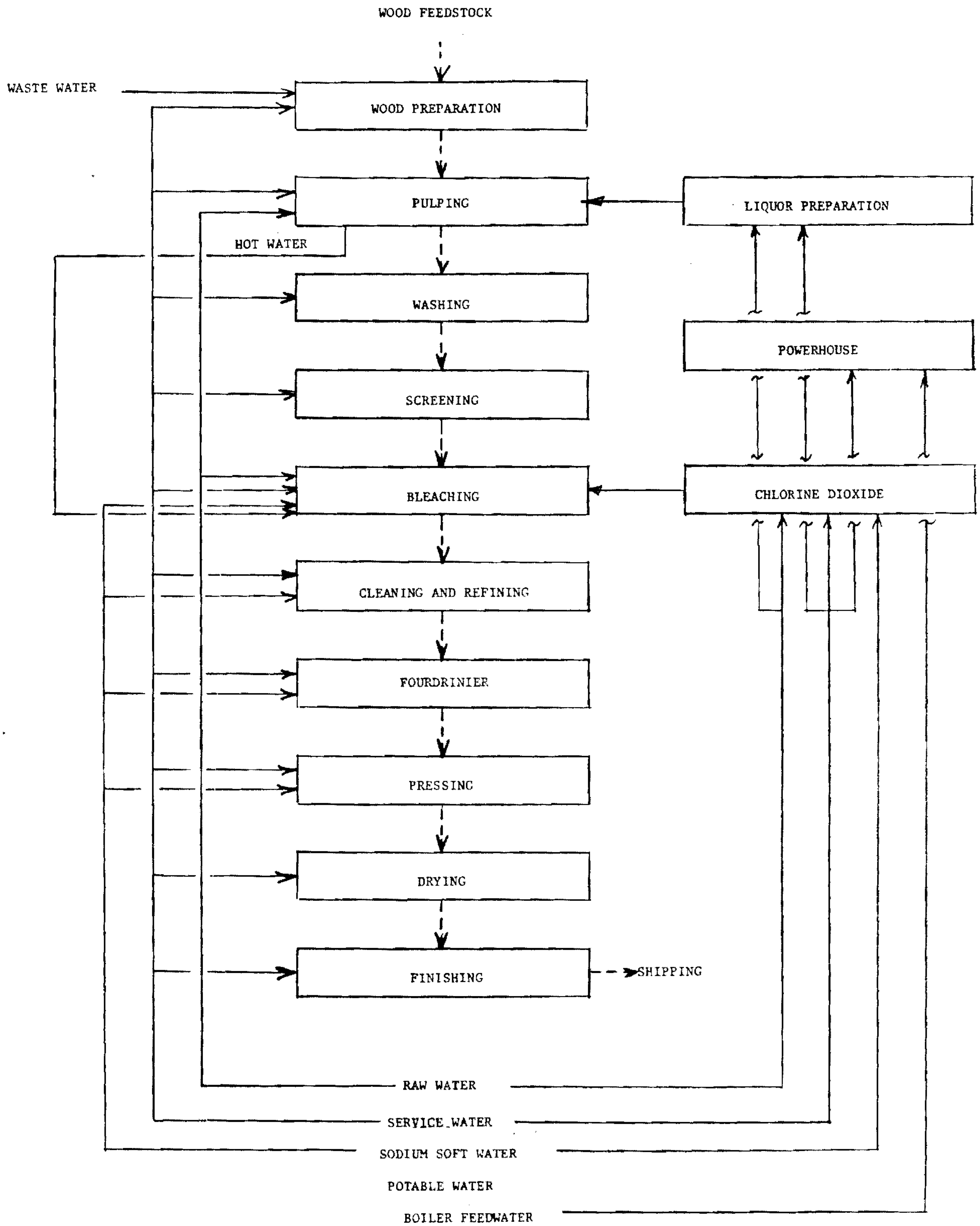


FIGURE 4

DIAGRAM OF SEMICHEMICAL-CHEMIMECHANICAL PULPING/PAPER PROCESS

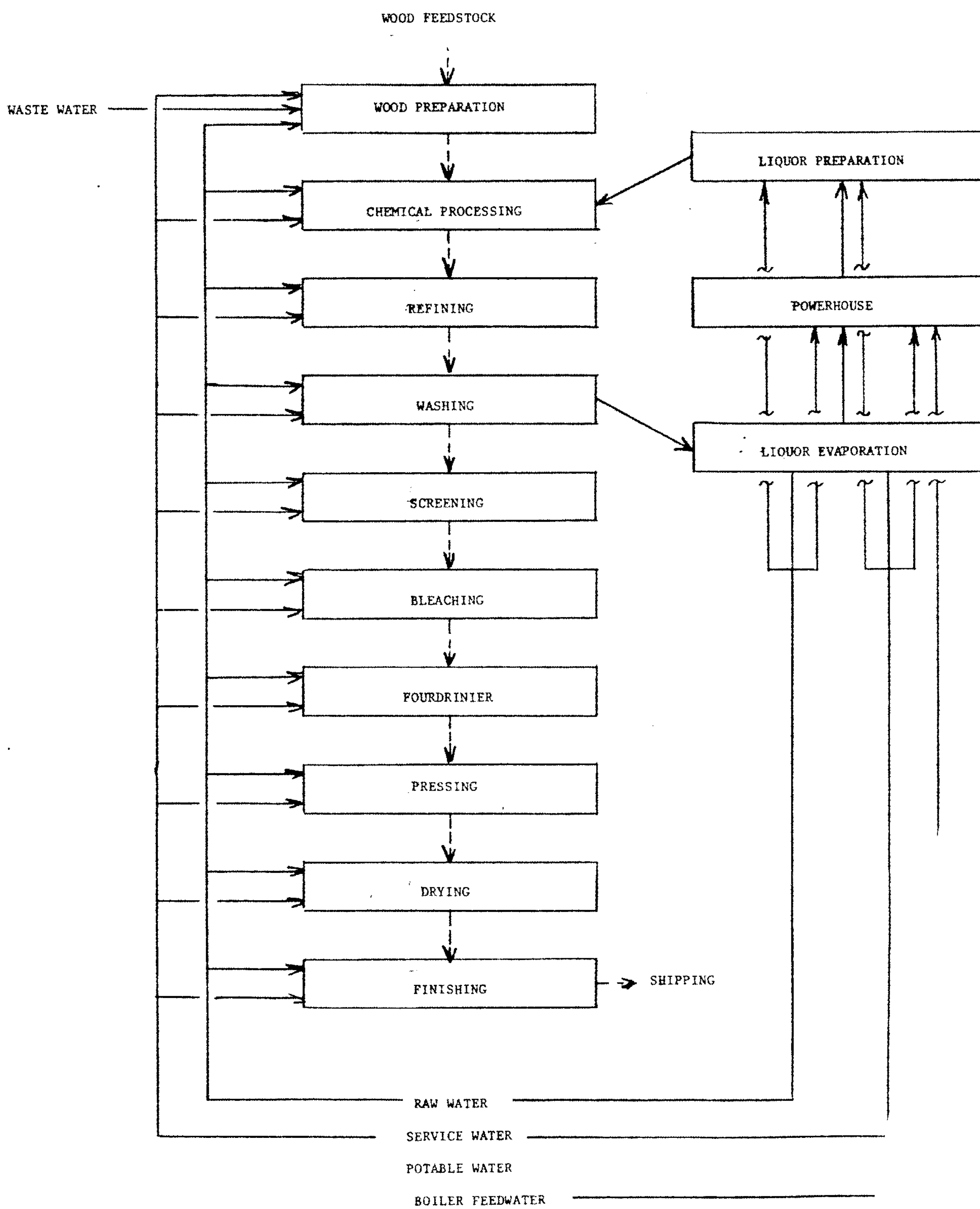


FIGURE 5

DIAGRAM OF MECHANICAL PULPING/PAPER PROCESS

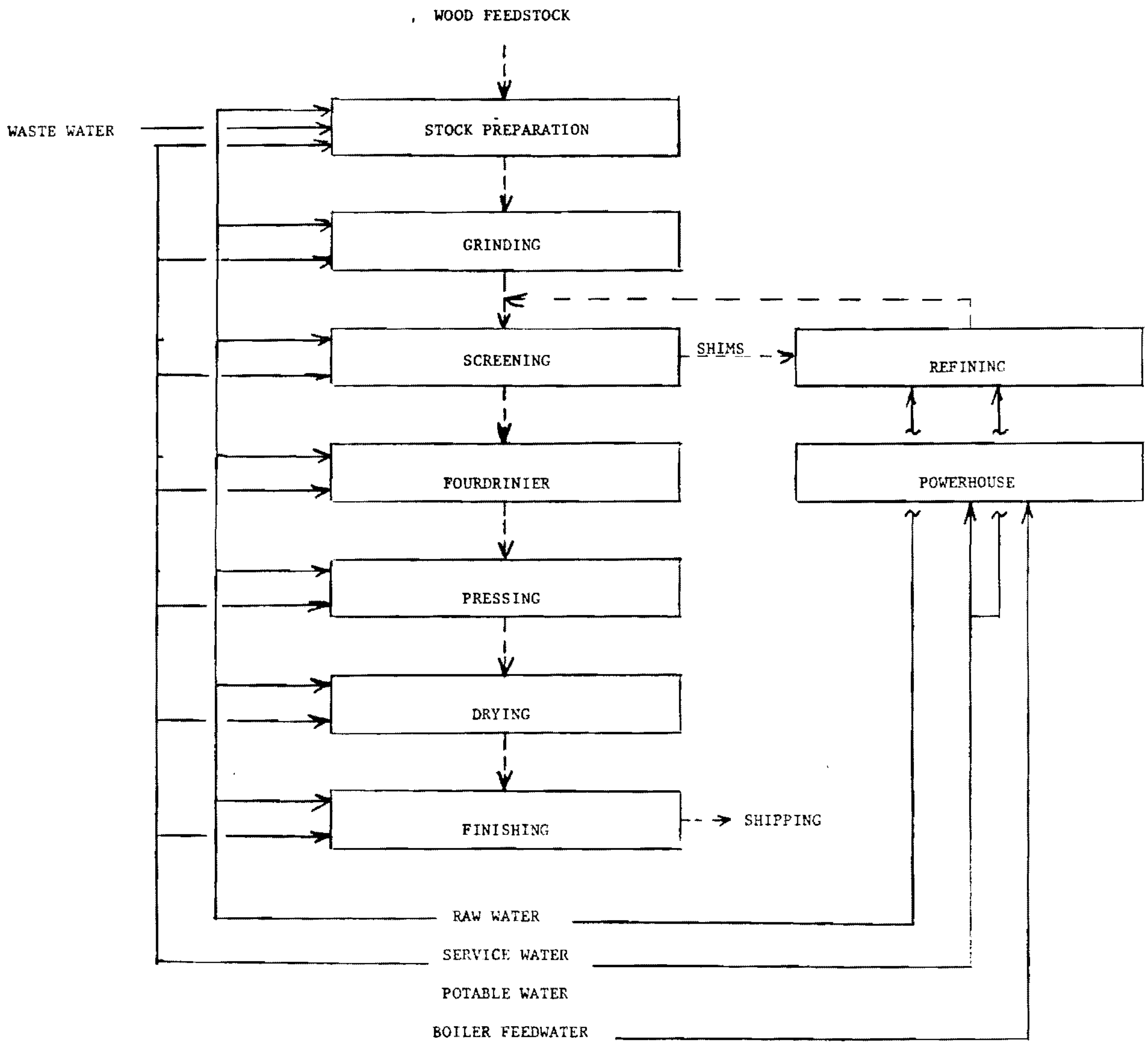
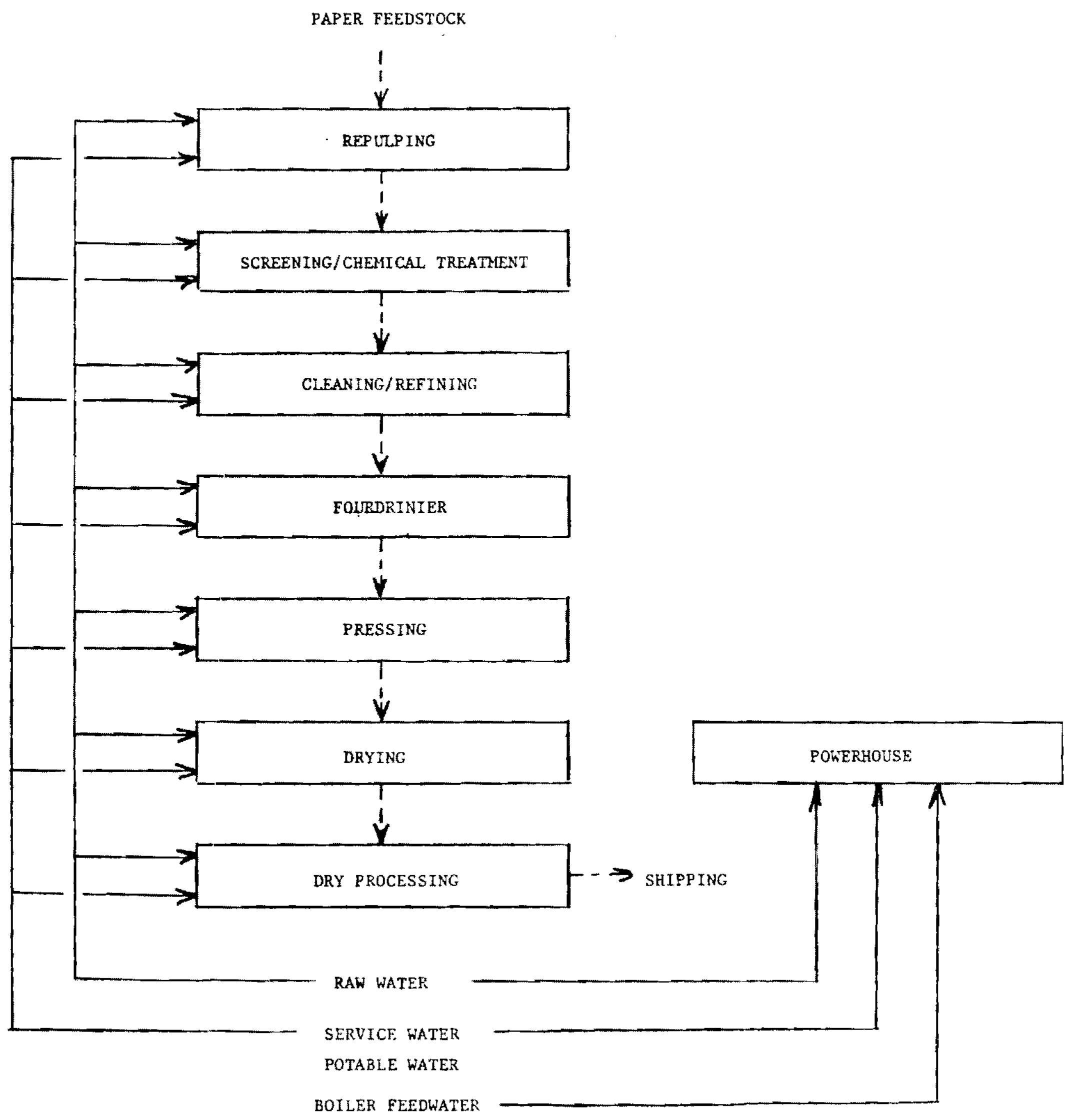


FIGURE 6

DIAGRAM OF PAPER FINISHING PROCESS



tinue as additional information from plants and other sources is reviewed. These diagrams will also serve as the point of data transferal to the computer model. As such, not only will product and resource quantities be defined but subprocess limitations and constraints will also be identified and added.

COMPUTER MODEL ACQUISITION

The study team has successfully acquired the "GEMS" computer model which will be used in evaluating the potential for water reuse.

GEMS is an acronym for General Energy and Material-Balance System. Its purpose is to calculate detailed material and energy balances for pulp and paper mills (either entire mills or specific parts of mills). The modular structure of GEMS makes it possible to do these calculations for almost any mill with no computer programming. Only engineering data needs to be provided. GEMS makes possible detailed balance calculations for many design or retrofit alternatives at a very low cost. To date GEMS has been applied to both bleached and unbleached kraft mills, sulfite mills, oxygen bleaching systems, mechanical and semi-chemical pulp mills, paper machines and various combinations of the above.

GEMS consists of an executive program and a set of generalized blocks representing each of the basic processing steps in a pulp and paper mill. In practice the engineer connects subroutines in a way that represents the mill flow sheet being studied and provides the executive program input flow rates, chemical charges, and other pertinent engineering information. The sequence and method of calculations are identical to hand calculations, but much faster. When the steady state calculation is complete, liquor flow rates, pulp consistencies, pulp composition (e.g. long fiber fraction and fines fraction) chemical compositions, and temperature for all process streams are provided to the engineer for analysis.

GEMS has the ability to create macro-blocks which are made up of a particular configuration of blocks. The program is also quite versatile and can be used to represent virtually all aspects of a mills operation including digestion, evaporation, washing, etc. The major challenge that lies ahead in using the program is in arranging the existing subroutines into a manner truely representative of an actual plant. Writing major new subroutines will not be necessary since the program is written in a sufficiently general manner to allow its operation using a number of different input parameters and constraints including those for water.

Appendix A displays an exercise performed on the model to gain familiarity with its operation.

PERSONNEL CHANGES AND FUTURE PLANS

As reported in an October 14 letter, there have been a few necessary changes in the study team membership brought about by recent personnel turnover. These changes are detailed in the letter and will not be repeated here. However it should be emphasized that the new project team has strong creditials in all areas necessary to successfully complete this research effort. No negative impact is anticipated on project performance.

Work to be conducted in the second quarter will focus on concluding further characterization detail, scheduling visits to plants both to collect specific performance data and to determine the manner in which water is currently reused, using assembled data to operate the computer model in making preliminary calculations of necessary process water demand, and assembling a list of major constraints which impact the degree to which water can be further reused by the pulp and paper industry.

APPENDIX A

COMPUTER OPERATION EXERCISE USING "GEMS"

The simulation example presented in this appendix is the "PMILL" exercise listed in the GEMS operating manual, but with the Bounded Wegstein convergence criteria added. Convergence is achieved in 46 iterations, down from 99 without acceleration. The simulation is designed to determine the salt cake loss at a dilution factor of 2.06 for 750 ODMT/day production of bleachable grade brown stock.

PMILL EXERCISE

PROBLEM STATEMENT

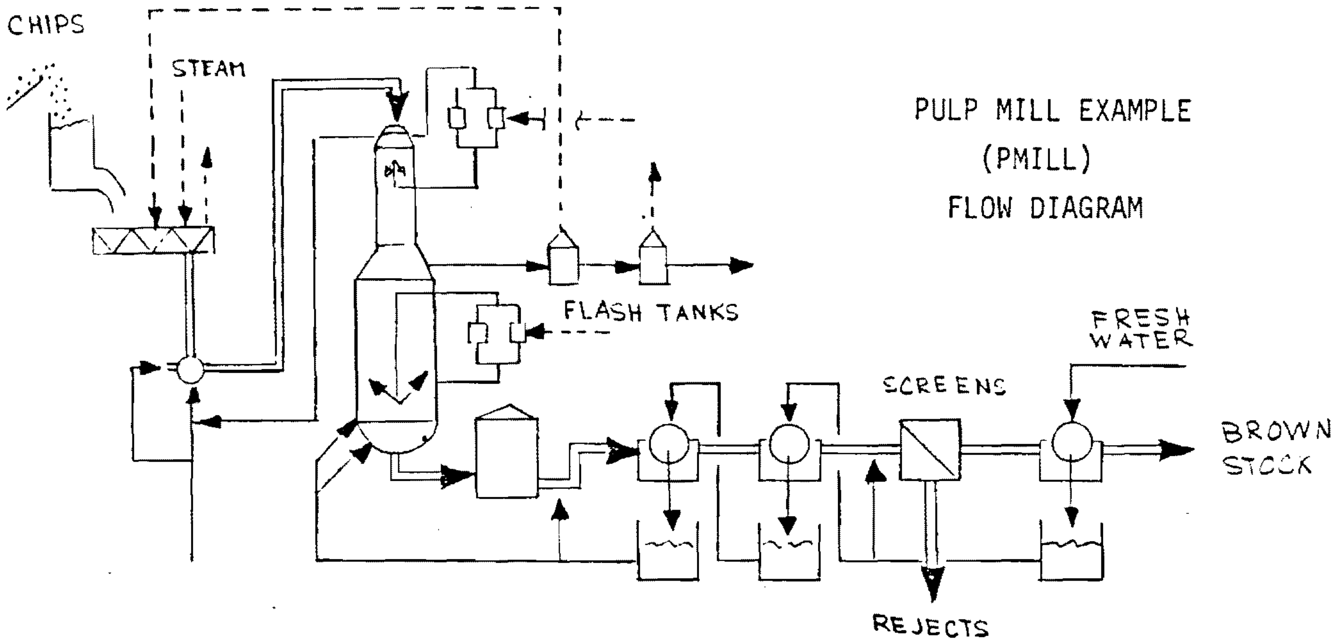
Given the pulp mill flow diagram presented on the next page for a 750 ODMT/day production of bleachable grade brown stock, determine the salt cake loss at a dilution factor of 2.06 (Decker shower flow = 604 GPM fresh water).

The GEMS block diagram for the PMILL example is also shown on the next page. The system consists of a continuous digester with two flashtanks, brown stock washers, screen room, and a washing decker.

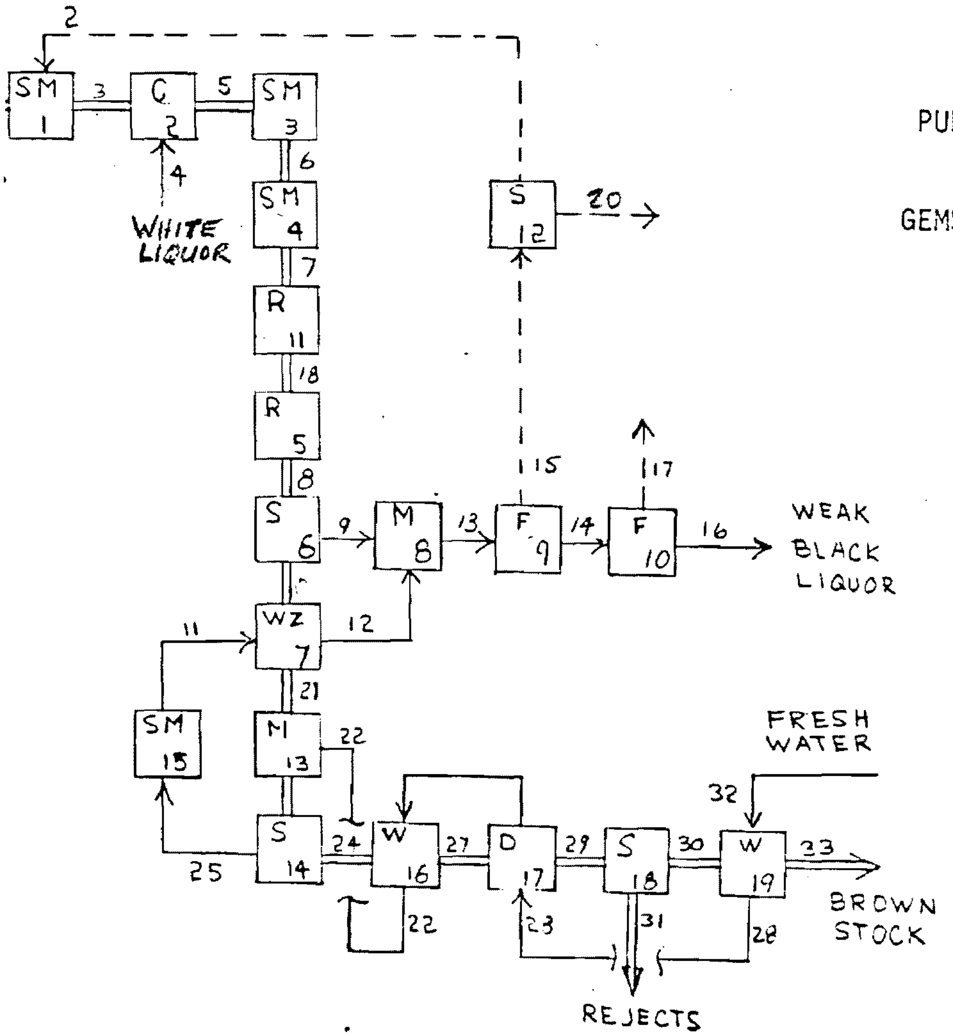
INPUT DATA AND ASSUMPTIONS

Incoming wood chips	3140.7 MT/day at 50% moisture
Effective alkali	90.0 grams NaOH/l
Sulfidity	25%
Reduction Efficiency	95%
Caustisizing Degree	80%
Brown Yield	48%
Cooking temperature	170°C
1st flash tank pressure	15.3 psig
2nd flash tank pressure	atmosphere
Blow line consistency	10%
Wash liquor heater temperature	130°C
Washing E factors	
Brown Stock (two stages)	E = 4
Decker	E = 1.5
Screen Rejects	0.5% of brownstock (at 20% consist.)

PULP MILL EXAMPLE
(PMILL)
FLOW DIAGRAM



PULP MILL EXAMPLE
(PMILL)
GEMS BLOCK DIAGRAM



```
 C,PMILL
 EOI.    O FILES.   O RECS.       O WORDS.
/GET,PMILL
/R,PMILL
R,PMILL.
/C,PMILL
 PULP MILL SIMULATION
 $CONTRL LOOPS=200,KPORT=0,IDCHK=1,MODZ=12,ITSTRT=18,$END
 $EQPMAX NEB=19,NSN=33,NSVS=2,$END
 $DATA KK=10,IDIS=4,ICO3=5,IS2=6,INA=7,IOH=8,ISO4=9,ICL=10, $END
 $P NE=1,NAME=STMIX,KP=1,2,-3,EQP(1)=1,2,1,$END
 $P NE=2,NAME=CHARGE,KP=3,4,-5,EQP(1)=6,0,0,.17,90,.25,.95,.8,80,1,$END
 $P NE=3,NAME=STMIX,KP=5,-6,EQP(1)=4,0,0,130,8530,$END
 $P NE=4,NAME=STMIX,KP=6,-7,EQP(1)=4,0,0,170,8530,$END
 $P NE=5,NAME=REACT,KP=18,-8,EQP(1)=25,0,0,12,4.52,$END
 $P NE=6,NAME=SPLIT,KP=8,-10,-9,EQP(1)=3,.3,0,1,$END
 $P NE=7,NAME=WZONE,KP=10,11,-21,-12,EQP(2)=0.2,$END
 $P NE=8,NAME=MIXER,KP=9,12,-13,$END
 $P NE=9,NAME=FLASH,KP=13,-14,-15,EQP(1)=0,1551,0,0,0,4.015,6.025,$END
 $P NE=10,NAME=FLASH,KP=14,-16,-17,EQP(1)=0,760,0,0,0,4.01,6.02,$END
 $P NE=11,NAME=REACT,KP=7,-18,EQP(7)=4.80,8.0,$END
 $P NE=12,NAME=SPLIT,KP=15,-20,-2,EQP(1)=2,0,.3,.3,$END
 $P NE=13,NAME=MIXER,KP=21,22,-23,$END
 $P NE=14,NAME=SPLIT,KP=23,-24,-25,EQP(1)=3,.1,0,1,$END
 $P NE=15,NAME=STMIX,KP=25,-11,EQP(1)=4,0,0,130,3860,$END
 $P NE=16,NAME=WASH,KP=24,26,-27,-22,EQP(1)=4.,.12,$END
 $P NE=17,NAME=DILUTE,KP=27,28,-29,-26,EQP(1)=2,.015,$END
 $P NE=18,NAME=SPLIT,KP=29,-31,-30,EQP(1)=3,.2,0,.005,$END
 $P NE=19,NAME=WASH,KP=30,32,-33,-28,EQP(1)=1.5,.12,$END
 $S NS=1,STV=65.4318,1.,20.,$END
 $S NS=32,STV=293.50,0.,40.,$END
 LIQUOR MTON/HR
 PULP   (MTON/TL)
 TEMP(C)
 DIS WOOD KG/TL
 CO3     KG/T LIQ
 SULFIDE (KGG/TL)
 NA      KG/T LIQ
 OH      KG/T LIQ
 SO4     KG/T LIQ
 CL      KG/T LIQ
 $CORDER NECALL=1,2,3,4,11,5,6,7,8,9,10,12,13,14,15,16,17,18,19,
 NEMODE(19)=3,$END
 EOI.   0 FILES.   1 RECS.    170 WORDS.
/
```

PULP MILL SIMULATION

READ DATA SET : CONTRL

```
DYNA=0          FACT1= -150.  FACT2=    0.  IAUTO=1       IRUG=    0
IFPR=0          IREAD= 1      ITSTRT=   18  KOP=11        KPORT= 0
LOOPS= 200      MACRO= 0      MAXERR= 50    MODZ=12       NFILE= 0
NPRINT=10000
```

CONVERGENCE CRITERIA

VARIABLE	DEL	VARIABLE	DEL
1	.0010	8	.0010
2	.0010	9	.0010
3	.0010	10	.0010
4	.0010	11	.0010
5	.0010	12	.0010
6	.0010	13	.0010
7	.0010	14	.0010

READ DATA SET : EQPMAX

PROCESS CONSISTS OF : 19 EQUIPMENT BLOCKS
33 STREAMS
2 STREAMS WITH SPECIFIED VARIABLES

EQUIPMENT BLOCKS AVAILABLE : NUMBER AND NAME

1	REACT	2	MIXER	3	SPLIT
4	HEATX	5	STMIX	6	CTRL
7	EVAPS	8	KFURN	9	SLAC
10	KILN	11	MGSFURN	12	LTV
13	DILUTE	14	U2ONE	15	TURB
16	GREC	17	VRC	18	SCTRL
19	SDT	20	CFST	21	PLUGF
22	SALTRM	23	CHARGE	24	WASH
25	FLASH	26	EECTRL	27	EDCTRL
28	HEADER	29	PDROP	30	PBOIL
31	HREC	32	CND	33	DESUP
34	GCTRL	35	PUMP	36	

```
INA= 7         IOH= 8         IDIS= 4        IS2= 6         IS04= 9
ICL=10         ICO3= 5
AX( 7)= 2.43   BX( 7)= 53.0

READ PROCES INFORMATION FROM INPUT DATA

NE=  1    NAME=STMIX       KP=   1   2  -3   0   0   0
     EQP=     1.000     2.000     1.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000

NE=  2    NAME=CHARGE      KP=   3   4  -5   0   0   0
     EQP=     6.000     0.000     0.000      .170    90.000      .250      .950      .800    80.000     1.000

NE=  3    NAME=STMIX       KP=   5  -6   0   0   0   0
     EQP=     4.000     0.000     0.000   130.000  8530.000     0.000     0.000     0.000     0.000     0.000

NE=  4    NAME=STMIX       KP=   6  -7   0   0   0   0
     EQP=     4.000     0.000     0.000   170.000  8530.000     0.000     0.000     0.000     0.000     0.000

NE=  5    NAME=REACT       KP=  18  -8   0   0   0   0
     EQP=    25.000     0.000     0.000    12.000     4.520     0.000     0.000     0.000     0.000     0.000

NE=  6    NAME=SPLIT       KP=   8 -10  -9   0   0   0
     EQP=     3.000      .300     0.000     1.000     0.000     0.000     0.000     0.000     0.000     0.000

NE=  7    NAME=WZONE       KP=  10  11 -21 -12   0   0
     EQP=     0.000      .200     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000

NE=  8    NAME=MIXER       KP=   9  12 -13   0   0   0
     EQP=     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000

NE=  9    NAME=FLASH       KP=  13 -14 -15   0   0   0
     EQP=     0.000  1551.000     0.000     0.000     0.000     4.015     6.025     0.000     0.000     0.000

NE= 10    NAME=FLASH       KP=  14 -16 -17   0   0   0
     EQP=     0.000   760.000     0.000     0.000     0.000     4.010     6.020     0.000     0.000     0.000

NE= 11    NAME=REACT       KP=   7 -18   0   0   0   0
     EQP=     0.000     0.000     0.000     0.000     0.000     0.000     4.800     8.000     0.000     0.000

NE= 12    NAME=SPLIT       KP=  15 -20  -2   0   0   0
     EQP=     2.000     0.000      .300      .300     0.000     0.000     0.000     0.000     0.000     0.000

NE= 13    NAME=MIXER       KP=  21  22 -23   0   0   0
     EQP=     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000

NE= 14    NAME=SPLIT       KP=  23 -24 -25   0   0   0
     EQP=     3.000      .100     0.000     1.000     0.000     0.000     0.000     0.000     0.000     0.000

NE= 15    NAME=STMIX       KP=  25 -11   0   0   0   0
     EQP=     4.000     0.000     0.000   130.000  3860.000     0.000     0.000     0.000     0.000     0.000

NE= 16    NAME=WASH        KP=  24  26 -27 -22   0   0
     EQP=     4.000      .120     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000

NE= 17    NAME=DILUTE      KP=  27  28 -29 -26   0   0
     EQP=     2.000      .015     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000

NE= 18    NAME=SPLIT       KP=  29 -31 -30   0   0   0
     EQP=     3.000      .200     0.000      .005     0.000     0.000     0.000     0.000     0.000     0.000

NE= 19    NAME=WASH        KP=  30  32 -33 -28   0   0
     EQP=     1.500      .120     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000
```

READ STREAM INFORMATION FROM INPUT DATA

NS= 1	STV=	65.432	1.000	20.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NS= 32	STV=	293.500	0.000	40.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

READ DATA SET : CORDER

1

PROCESS MATRIX

NO.	NAME	MODE	CORDER	MODE	STREAMS IN AND OUT					
1	STMIX	2	1	2	1	2	-3	0	0	0
2	CHARGE	2	2	2	3	4	-5	0	0	0
3	STMIX	2	3	2	5	-6	0	0	0	0
4	STMIX	2	4	2	6	-7	0	0	0	0
5	REACT	2	11	2	18	-8	0	0	0	0
6	SPLIT	2	5	2	8	-10	-9	0	0	0
7	WZONE	2	6	2	10	11	-21	-12	0	0
8	MIXER	2	7	2	9	12	-13	0	0	0
9	FLASH	2	8	2	13	-14	-15	0	0	0
10	FLASH	2	9	2	14	-16	-17	0	0	0
11	REACT	2	10	2	7	-18	0	0	0	0
12	SPLIT	2	12	2	15	-20	-2	0	0	0
13	MIXER	2	13	2	21	22	-23	0	0	0
14	SPLIT	2	14	2	23	-24	-25	0	0	0
15	STMIX	2	15	2	25	-11	0	0	0	0
16	WASH	2	16	2	24	26	-27	-22	0	0
17	DILUTE	2	17	2	27	28	-29	-26	0	0
18	SPLIT	2	18	2	29	-31	-30	0	0	0
19	WASH	3	19	3	30	32	-33	-28	0	0

1

```
STREAM VARIABLES

        LIQUOR MTON/HR    PULP  (MTON/TL)    TEMP(C)             DIS WOOD KG/TL    CO3    KG/T LIQ
        SULFIDE (KGG/TL   NA      KG/T LIQ   OH      KG/T LIQ    SO4    KG/T LIQ   CL     KG/T LIQ

   1     65.43180          1.000000           20.00000           0.                0.
        0.                0.                 0.                  0.                0.

  32     293.5000         0.                  40.00000           0.                0.
        0.                0.                 0.                  0.                0.


     DATA INPUT WITH     0 ERRORS

     SUCCESSFUL DATA ENTRY :  PROCEED WITH EXECUTION
     CONVERGENCE ACCELERATION ON THE FOLLOWING STREAMS:
      2, 11, 22, 26, 28,

     BEGIN ACCELERATION ON ITERATION NO.   18     WITH MODZ = 12
1
     BEGIN ENERGY AND MATERIAL BALANCES


     BEGIN ITERATION WITH THE FOLLOWING BLOCKS:
           1,  2,  3,  4, 11,  5,  6,  7,  8,  9, 10, 12, 13, 14, 15,
          16, 17, 18, 19,

ERRORS FOR ITERATION   1 ARE :    10503   71401  140302  150501  162401  171302

ERRORS FOR ITERATION   2 ARE :    71401  140302  150501  162401

ERRORS FOR ITERATION   3 ARE :    71401  140302  150501  162403

ERRORS FOR ITERATION   4 ARE :    71401  140302  150501

ERRORS FOR ITERATION   5 ARE :    71401  140302  150501

ERRORS FOR ITERATION   6 ARE :    71401
```

NAME	NO.	PARAMETERS				
STMIX	1	1.00000	2.00000	1.00000	0.	0.
		0.	0.	0.	0.	0.
CHARGE	2	6.00000	0.	0.	.170000	90.0000
		.250000	.950000	.800000	80.0000	2.00000
STMIX	3	4.00000	0.	0.	130.000	8530.00
		0.	0.	0.	15.8397	7541.70
STMIX	4	4.00000	0.	0.	170.000	8530.00
		0.	0.	0.	19.3044	9191.38
REACT	5	25.0000	0.	0.	12.0000	4.52000
		0.	0.	0.	0.	0.
SPLIT	6	3.00000	.300000	0.	1.00000	0.
		0.	0.	0.	0.	0.
WZONE	7	0.	.200000	0.	0.	0.
		1.86927	.814708	0.	2.02831	0.
MIXER	8	0.	0.	0.	0.	0.
		0.	0.	0.	0.	0.
FLASH	9	0.	1551.00	0.	0.	0.
		4.01500	6.02500	0.	0.	0.
FLASH	10	0.	760.000	0.	0.	0.
		4.01000	6.02000	0.	0.	0.
REACT	11	0.	0.	0.	0.	0.
		0.	4.80000	8.00000	0.	0.
SPLIT	12	2.00000	0.	.300000	.300000	0.
		0.	0.	0.	0.	0.
MIXER	13	0.	0.	0.	0.	0.
		0.	0.	0.	0.	0.
SPLIT	14	3.00000	.100000	0.	1.00000	0.
		0.	0.	0.	0.	0.
STMIX	15	4.00000	0.	0.	130.000	3860.00
		0.	0.	0.	10.8778	5467.15
WASH	16	4.00000	.120000	0.	0.	0.
		0.	0.	0.	.894293	1.27659
DILUTE	17	2.00000	.150000E-01	0.	0.	0.
		0.	0.	0.	0.	0.
SPLIT	18	3.00000	.200000	0.	.500000E-02	0.
		0.	0.	0.	0.	0.
WASH	19	1.50000	.120000	0.	0.	0.
		0.	0.	0.	.672150	1.28072

	LIQUOR (MTON/HR SULFIDE (KGG/TL	PULP (MTON/TL) NA KG/T LIQ	TEMP(C) OH KG/T LIQ	DIS WOOD KG/TL SO4 KG/T LIQ	CO3 KG/T LIQ CL KG/T LIQ
1	65.43180	1.000000	20.00000	0.	0.
	0.	0.	0.	0.	0.
2	16.56516	1551.000	122.8125	24.03049	0.
	1.356232	0.	0.	0.	0.
3	81.99699	.7979791	117.7133	4.854431	0.
	.2739741	0.	0.	0.	0.
4	135.9527	0.	80.00000	0.	13.14935
	9.350649	64.55495	34.77273	1.476418	0.
5	217.9497	.3002151	97.17924	1.826333	8.202305
	5.935825	39.53887	21.69054	.9209606	0.
6	217.9497	.3002151	130.0000	1.826333	8.202305
	5.935825	39.53887	21.69054	.9209606	0.
7	217.9497	.3002151	170.0000	1.826333	8.202305
	5.935825	39.53887	21.69054	.9209606	0.
8	251.9743	.1246447	173.7018	151.6208	7.094733
	5.134300	34.52796	.1636098	.7966016	0.
9	178.6907	0.	173.7018	151.6208	7.094733
	5.134300	34.52796	.1636098	.7966016	0.
10	73.28362	.4285714	173.7018	151.6208	7.094733
	5.134300	34.52796	.1636098	.7966016	0.
11	136.9871	0.	130.0000	22.86370	1.069848
	.7742303	5.216109	.2467324E-01	.1201233	0.
12	136.9871	0.	155.5833	78.97171	3.695289
	2.674202	17.98920	.8521753E-01	.4149097	0.
13	315.6778	0.	165.5314	120.0950	5.619558
	4.066750	27.35097	.1295918	.6309679	0.
14	292.0133	0.	122.8125	129.8274	6.074962
	4.396316	29.45757	.1400938	.6821010	0.
15	23.66452	1551.000	122.8125	24.03049	0.
	1.356232	0.	0.	0.	0.
16	281.4168	0.	101.6837	134.7160	6.303710
	4.561855	30.47553	.1453689	.7077849	0.
17	10.59649	760.0000	101.6837	35.77725	0.
	2.423034	0.	0.	0.	0.
18	217.9497	.3002151	170.0000	19.17877	8.202305
	5.935825	39.53887	4.338108	.9209606	0.
20	7.099355	1551.000	122.8125	24.03049	0.
	1.356232	0.	0.	0.	0.

21	73.28362	.4285714	130.0000	46.70720	2.185547
	1.581637	10.64415	.5040238E-01	.2453948	0.
22	346.3689	0.	79.58624	17.83140	.8343740
	.6038224	4.070057	.1924245E-01	.9368410E-01	0.
23	419.6525	.7484112E-01	89.29445	22.86370	1.069848
	.7742303	5.216109	.2467324E-01	.1201233	0.
24	282.6654	.1111111	89.29445	22.86370	1.069848
	.7742303	5.216109	.2467324E-01	.1201233	0.
25	136.9871	0.	89.29445	22.86370	1.069848
	.7742303	5.216109	.2467324E-01	.1201233	0.
26	294.0235	0.	48.28390	3.570885	.1670895
	.1209208	.8223804	.3852764E-02	.1876092E-01	0.
27	230.3199	.1363636	53.02903	5.804512	.2716063
	.1965578	1.334489	.6263199E-02	.3049615E-01	0.
28	2126.114	0.	48.28399	3.569728	.1670354
	.1208816	.8221178	.3851566E-02	.1875485E-01	0.
29	2062.410	.1522843E-01	48.83534	3.820326	.1787614
	.1293676	.8798312	.4121949E-02	.2007146E-01	0.
30	2061.782	.1515690E-01	48.83534	3.820326	.1787614
	.1293676	.8798312	.4121949E-02	.2007146E-01	0.
31	.6281453	.2500000	48.83534	3.820326	.1787614
	.1293676	.8798312	.4121949E-02	.2007146E-01	0.
32	293.5000	0.	40.00000	0.	0.
	0.	0.	0.	0.	0.
33	229.1683	.1363636	42.89667	1.252495	.5860697E-01
	.4241319E-01	.3010396	.1351382E-02	.6580432E-02	0.

EOI. 0 FILES. 1 RECS. 2697 WORDS.

APPENDIX B

END-OF-PIPE TREATMENT TECHNOLOGIES COMMONLY EMPLOYED BY THE PULP, PAPER, AND PAPERBOARD INDUSTRY

Many types of wastewater treatment systems are employed at mills in the pulp, paper, and paperboard industry. This section describes the treatment systems employed by the industry and presents information on other applicable effluent treatment technologies.

Preliminary/Primary Treatment

Wastewater must often be screened to remove materials that could seriously damage or clog downstream treatment equipment. Automatically cleaned screens are commonly employed prior to primary treatment and generally represent the preferred practice.

Reproduced from - "Development Document for Proposed Effluent Limitations Guidelines and Standards for the Pulp, Paper and Paperboard and the Builders' Paper and Board Mills." U.S. Environmental Protection Agency, December 1980, pp 306-357.

The initial process of removing organic and inorganic solids can be accomplished by sedimentation (with or without flocculants or coagulants), flotation, or filtration. Primary treatment can involve mechanical clarifiers, flotation units, or sedimentation lagoons.

The most widely applied technology for removing solids from pulp, paper, and paperboard mill wastewaters is the mechanical clarifier. In the mechanical clarifier, solids are removed by simple sedimentation. Dissolved air flotation (DAF) units have also been applied to remove solids from paper mill effluents.(81) DAF units are somewhat limited in use because of their inability to handle high pollutant concentrations and shock loads. Fine screens, microstrainers, and pressure filters are not commonly used in the industry for solids removal. Adequate fine screening systems cost approximately the same as an equivalent clarifier and reportedly have more inherent operating problems.(82)

Because of the biodegradable nature of a portion of the settleable solids present in pulp, paper, and paperboard mill wastewaters, clarification can result in some BOD5 reduction. Typical BOD5 removal through primary clarification of integrated pulp and paper mill effluent can vary between 10 and 30 percent. The exact BOD5 removal depends on the percentage of soluble BOD5 present in the raw wastewater. Primary clarification can result in significantly higher BOD5 reductions at nonintegrated mills than at integrated mills. Responses to the data request program indicate that approximately 50 percent of the raw wastewater BOD5 is commonly removed at nonintegrated mills through the application of primary clarification.

Easty has recently observed that very little reduction of fatty acids, resin acids, or their chlorinated derivatives occurs during primary clarification.(83) This observation suggests that these compounds are not associated with the raw wastewater solids measured in the TSS test procedure. Polychlorinated bi-phenyls (PCBs) have been observed to undergo significant reductions through primary treatment.(10) At a wastepaper tissue mill, PCBs were reduced from 25 to 2.2 micrograms per liter (ug/l) through primary clarification, while TSS were reduced from 2,020 to 77 milligrams per liter (mg/l).(10) It has not yet been established whether reductions occur for other chloro-organic compounds.

Biological Treatment

Currently, the most common types of biological treatment used in the pulp, paper, and paperboard industry include oxidation basins, aerated stabilization basins, and the activated sludge process or its modifications. Other biological systems that have been used include rotating biological contactors and anaerobic contact filters.

A principal benefit obtained from biological treatment is the reduction of oxygen demand. Significant reductions in toxic pollutants have also been observed through application of biological treatment as illustrated by recent data gathering efforts (see Section

VI. Biological treatment systems have been designed and operated to achieve 80 to 90 percent and higher BOD5 reductions when applied to pulp, paper, and paperboard mill effluents. Biological treatment can also yield a nontoxic effluent a high percentage of the time.(84)

Due to the fluctuation of influent wastewater characteristics, specific toxic pollutant removal capabilities are not readily measureable unless long-term field sampling is employed. In a laboratory study, Leach, Mueller, and Walden determined the specific biodegradabilities of six nonconventional pollutants in pulp, paper, and paperboard mill wastewaters.(85) The relative ease with which these six compounds were degraded was, in descending order: dehydroabietic acid, pimaric acid, tetrachloroguiacol, monochlorodehydroabietic acid, dichlorodehydroabietic acid, and trichloroguaiacol. The researchers reported that chlorinated bleach plant derivatives are more difficult to degrade than are the nonchlorinated wood derivatives.

A recent study involved investigation of influent and effluent concentrations of toxic and nonconventional pollutants after full-scale biological treatment.(83) Removal rates of these pollutants, as derived from the published design and treatment data, are shown in Table VII-5.(83) The relative removal rates generally agree with those obtained in laboratory studies.(83)(85)

BOD5 and toxic pollutant removals from bleached kraft wastewater through application of activated sludge treatment and aerated stabilization were investigated in an attempt to establish a relation between pollutant concentration and toxicity.(84) The authors concluded that, in general, a reduction in BOD5 to about 45 mg/l was sufficient to achieve detoxification of the waste. Also, a total resin and fatty acid concentration of less than 1 mg/l was necessary to effect detoxification. The correlation between total resin and fatty acid content and toxicity was better than the correlation between BOD5 and toxicity.

Oxidation Basins. The first type of biological treatment systems used in the pulp, paper, and paperboard industry were oxidation basins. These are large natural or manmade basins of various depths; natural aeration from the atmosphere is relied on as the primary oxygen source. Additionally, limited oxygen is provided by algal photosynthesis. The amount of oxygen provided through photosynthesis is dependent upon the basin configuration (depth) and its restriction in light penetration. Since oxidation through natural aeration is a relatively low-rate process, large land areas are required to effectively treat high strength wastes. Because of availability of land and a warm climate that enhances bioactivity, most oxidation basins are found in southern states. This technology can be more effective if settleable solids are removed from the wastewater prior to discharge to the basins. Solids can contribute significantly to the BOD5 wastewater loads. In addition, excess settleable solids tend to fill the basins, thus reducing detention time.

TABLE VII-5

CALCULATED TOXIC AND NONCONVENTIONAL POLLUTANT REMOVAL RATES(a)*

	Mill 9(b) 10-Day ASB	Mill 11(b) 6-Day ASB	Mill 12(c) 3.5-Hr AS	Mill 13(b) 12-Day ASB	Mill 14(b) 7-Day ASB	Mill 15(b) 15-Day ASB
Resin Acids						
Abietic	0.85	0.86	0.3	1.5	1.0	0.45
Dehydroabietic	1.05	2.65	0.6	1.85	1.1	0.72
Isopimaric	0.30	0.37	0.26	1.25	3.0	0.12
Pimaric	0.10	0.14	0.3	0.3	0.1	0.15
Unsaturated Fatty Acids						
Oleic		0.7	0.35	0.55		0.67
Linoleic		2.6	0.30	0.15		0.47
Linolenic		0.4				
Other Acidics						
Epoxysteric Acid						0.03
Dichlorosteric Acid				10.4		0.12
Chlorinated Resin Acids						
Monochlorodehydroabietic		0.10	0.006	0.03		0.01
Dichlorodehydroabietic		0.05	0.019	0.10		0.03
Chlorinated Phenolics						
Trichloroguaiacol		0.03				
Tetrachloroguaiacol		0.02				
Chloroform		2.2	2.1			

(a) Removal rates shown as micrograms removed per milligrams/liter (mg/l) of biomass per day.
(b) Aerated stabilization basin (ASB) biomass assumed to be 200 mg/l.
(c) Activated sludge (AS) biomass reported to be 2,500 mg/l.
NOTE: Blank spaces indicate no data.
*Source: Easty, Dwight B., L.G. Borcharot, and B.A. Wabers, Institute of Paper Chemistry, Removal of Wood Derived Toxics from Pulping and Bleaching Wastes, U.S. Environmental Protection Agency, Cincinnati, OH, EPA 60012-78-031, 1978.(83)

Typical design BOD_5 loads range from 56 to 67 kilograms per hectare (kg/ha) of surface area/day (50 to 60 lb/acre/day).(40) Retention times can vary from 20 to 60 days or more.(40) This method of treatment has two principal advantages: a) it can be capable of handling (buffering) accidental discharges of strong wastewater without significant upset and b) it requires no mechanical devices with inherent maintenance problems. Oxidation basins have been used to effectively treat pulp, paper, and paperboard industry wastewaters. Generally, suspended solids are effectively removed in oxidation basins. However, high levels of suspended solids have been noted due to algal carryover. Literature presenting data on the removal of toxic and nonconventional pollutants through application of oxidation basin technology is limited.

Aerated Stabilization Basins (ASBs). The aerated stabilization basin (ASB) evolved from the necessity of increasing performance of existing oxidation basins due to increasing effluent flows and/or more stringent water quality standards. Induced aeration provides a greater supply of oxygen, thus substantially reducing the retention time required to achieve treatment comparable to that attained in an oxidation basin. Nitrogen and phosphorus (nutrients) are usually added prior to the ASB if the wastewater is determined to be nutrient deficient. These additions are commonly made in the form of ammonia and phosphoric acid. The longer the retention period of the waste undergoing biological oxidation, the lower the nutrient requirement. The specific detention time used depends upon the characteristics of the wastewaters to be treated. Retention times of 8 to 10 days, and sometimes up to 15 days, have been used in order to obtain BOD_5 levels of less than 30 mg/l.(87)(88)(89) The specific detention time used depends upon the characteristics of the wastewaters to be treated.

Aeration is normally accomplished using either mechanical surface aerators or diffused air. Oxygen transfer efficiencies under actual operating conditions range from 0.61 to 1.52 kilograms (kg) of oxygen per kilowatt-hour (kwh), or about (1.0 to 2.5 lb of oxygen per horsepower-hour) depending on the type of equipment used, the amount of aeration power per unit volume, basin configuration, and the biological characteristics of the system.(90)(91) It is necessary to maintain a dissolved oxygen (DO) level of 0.2 to 0.5 mg/l in the basin to sustain aerobic conditions.

BOD_5 and suspended solids levels, oxygen uptake, and DO levels throughout the basins are related to aerator location and performance and basin configuration. There have been extensive studies of eleven existing aerated stabilization basins that have led to development of design criteria to aid in the design of future basins.(92)

Some solids accumulate in the bottom of ASBs that can be removed with periodic dredging. Solids accumulation diminishes as the detention time and degree of mixing within the basin increases. At some mills, a quiescent zone, settling basin, or clarifier is used to improve effluent clarity and to reduce suspended solids.

The toxicity removal efficiency of an ASB treating unbleached kraft waste was evaluated over a one-month period in late 1976.(93) Although the raw wastewater exhibited an LC-50 of from one to two percent by volume, all but one of the 26 treated effluent samples were either nontoxic or exhibited greater than 50 percent fish survival after 96 hours of exposure. The one failure was attributed to a black liquor spill at the mill. Average reductions of 87 percent BOD_5, 90 percent toxicity, and 96 percent total resin acids were achieved. Dehydroabietic acid was the only resin acid identified in the treated effluent; pimaric, isopimaric and abietic acids tended to concentrate in the foam from the effluent.

Pilot-scale ASB treatment of bleached kraft wastewater was evaluated over a five month period.(84) Two basins, one with a five day and one with a three day hydraulic detention time, were studied with and without surge equalization. The raw wastewater BOD_5 varied from 108 mg/l to 509 mg/l and was consistently toxic. The median survival times (MST) of fish ranged from 7 to 1,440 minutes, while total resin and fatty acid concentrations ranged from 2 to 8 mg/l.(84) Mean BOD_5 removals with surge equalization were 85 percent for the five day basin and 77 percent for the three day basin. Mean effluent BOD_5 levels with surge equalization were 40 mg/l for the five day basin and 59 mg/l for the three day basin. Detoxification was attained 98 percent of the time by the five day basin with surge equalization and 85 percent of the time by the three day basin with surge equalization. Mean reported effluent BOD_5 values for the five day and three day basins without equalization were 51 mg/l and 67 mg/l, respectively. The detoxification rate without equalization dropped to 73 percent for the five day basin and 70 percent for the three day basin. The authors concluded that surge equalization appeared to have a more significant effect on detoxification than BOD_5 removal. Since the surge capacity of an aerated stabilization basin is related to hydraulic detention time, the eight to ten day basins which are commonly employed in the pulp, paper, and paperboard industry in the United States could have a higher capacity for shock loading than those used in this study.

Aerated stabilization basins provide a high degree of BOD_5 reduction and also can remove or reduce the wastewater toxicity. ASB capital and operating costs may be lower than those for the activated sludge process. The treatment efficiency is not as dependent on ambient air temperature as with oxidation basins; however, efficiency can be more dependent on ambient air temperature for ASB's than for higher rate processes (i.e., activated sludge).

Activated Sludge Process. The activated sludge process is a high-rate biological wastewater treatment process. The biological mass (biomass) grown in the aeration basins is settled in a secondary clarifier and varying amounts of this biomass are returned to the aeration basins, building up a large concentration of active biological material. It is common to maintain 2,000 to 5,000 mg/l of active biological solids in the aeration basin section of the activated sludge system compared to the 50 to 200 mg/l common to aerated stabilization basins. Loadings in excess of 1.6 kilograms of BOD_5 per cubic meter (100 lbs of BOD_5 per 1,000 ft^3) of aeration capacity per day are sometimes used, allowing for relatively small aeration basins.

The characteristically short detention times tend to make the activated sludge process more susceptible to upset due to shock loads. When the process is disrupted, it may require several days for biological activity to return to normal. Particular operator attention is required to avoid such shock loadings at mills where this process is employed. The necessity for strict operator attention can be avoided through provision of sufficient equalization to minimize the effects of shock loadings.

Compared with aerated stabilization basins, the activated sludge process has less shock load tolerance, greater solids handling requirements, and higher costs. However, the activated sludge process requires less land than ASBs. Thus, it may be preferred in cases where sufficient land for ASB installation is either unavailable or too expensive.

The activated sludge process is very flexible and can be adapted to many waste treatment situations. The activated sludge process has many modifications that can be selected as most appropriate. Various types of activated sludge processes that have been applied to treat pulp, paper, and paperboard wastewaters include: a) conventional, b) complete-mix, c) tapered aeration, d) step aeration, e) modified aeration, f) contact stabilization, g) extended aeration, h) oxidation ditch, and i) pure oxygen. Another process, the Zurn-Attisholz process consists of a two stage system. Table VII-6 summarizes standard design parameters for the activated sludge process and several of its modifications.

In the conventional activated sludge process, both influent wastewater and recycled sludge enter the aeration basin at the head end and are aerated for a period of about four to eight hours or more. Mechanical surface aerators similar to those used in aerated stabilization basins are used; the use of diffused air is becoming more common. Normally, the oxygen demand decreases as the mixed liquor travels the basin length. The mixed liquor is settled and the activated sludge is generally returned at a rate of approximately 25 to 50 percent of the influent flow rate.

In the complete-mix activated sludge process, influent wastewater and recycled sludge enter the aeration basin at several points along the length of the basin. The mixed liquor is aerated at a constant rate as it passes from the central channel to effluent channels at both sides of the basin. The contents of the basin are completely mixed and the oxygen demand remains uniform throughout. The aeration period is from three to five hours, and the activated sludge is returned at a typical rate of 25 to 100 percent of influent flow rate.

TABLE VII-6

TYPICAL DESIGN PARAMETERS FOR ACTIVATED SLUDGE PROCESSES

	Parameter		
Process Modification	Volumetric loading (lb BOD5/1,000 cu ft)	MLSS (mg/l)	Detention Time V/Q (hr)
Conventional	20-40	1,500-3,000	4-8
Complete mix	50-120	3,000-6,000	3-5
Step aeration	40-60	2,000-3,500	3-5
Modified aeration	75-150	200-500	1.5-3
Contact stabilization	60-75	(1,000-3,000)*	(0.5-1.0)*
		(4,000-10,000).	(3-6).
Extended aeration	10-25	3,000-6,000	18-36
Pure oxygen systems	100-250	6,000-8,000	1-3

*Contact unit.
.Solids stabilization unit.
MLSS = Mixed Liquor Suspended Solids
V = Volume
Q = Flow

The tapered-aeration process is a modification of the conventional process with the primary difference being the amount of air supplied. At the head of the basin, where wastewater and returned sludge come into contact, more oxygen is required. As the mixed liquor traverses the aeration basin, the oxygen demand decreases so aeration is decreased. Since the oxygen supply is decreased with the oxygen demand, a lower overall oxygen requirement can be achieved.

The step-aeration process also is a modification of the conventional activated sludge process. In this modification, the wastewater is introduced at several points in a compartmentized basin while the return activated sludge is introduced at the head of the basin. Each compartment of the basin is a separate step with the several steps linked together in series. Aeration can be of the diffused or mechanical type and is constant as the mixed liquor moves through the tank in a plug-flow fashion. The oxygen demand is more uniformly spread over the length of the basin than in the conventional activated sludge process, resulting in better utilization of the oxygen supply. The aeration period is typically between three and five hours and the activated sludge is returned at a typical rate of 25 to 75 percent of influent flow rate.

The contact-stabilization process takes advantage of the absorptive properties of activated sludge through operation in two stages. The first is the absorptive phase in which most of the colloidal, finely suspended, and dissolved organics are absorbed in the activated sludge in a contact basin. The wastewater and return stabilized sludge enter at the head of the contact basin, are aerated for a period of 20 to 40 minutes, and settled in a conventional clarifier. The second stage is the oxidation phase, in which the absorbed organics are metabolically assimulated providing energy and producing new cells. In this stage, the settled solids from the absorptive stage are aerated for a period of from three to six hours in a stabilization basin. A portion of the solids are wasted to maintain a constant mixed liquor volatile suspended solids (MLVSS) concentration in the stabilization basin. Contact stabilization has been applied successfully at several facilities to treat kraft mill wastewaters.

The extended-aeration process is a complete-mix activated sludge process in which the aeration period is relatively long (24 to 48 hours) and the organic loading relatively low. Because of these conditions, the process is very stable and can accept intermittent loads with minimal or no upset. The solids settled in the clarifiers are recirculated to the influent of the aeration basins. Through this process, a mass of biological solids are built up in the aeration basin. This biomass assists in achieving high treatment efficiencies through removal of dissolved organic matter in the wastewater by oxidation. Excess secondary solids, if present, are wasted from the process. Oxygen may be provided by either mechanical or diffused aeration. This process has been applied successfully throughout the pulp, paper, and paperboard industry. In northern climates, where temperature can impact the system performance, the extended-aeration process offers the stability of an ASB system and the high treatment efficiency of the activated sludge process.

The oxidation ditch activated sludge process is an extended-aeration process in which aeration and circulation are provided by brush rotors placed across a race track-shaped basin. The wastewater enters the ditch at one end, is aerated, and circulates at about 0.3 to 0.6 meters per second (1 to 2 fps). Operation can be intermittent, in which case clarification takes place in the ditch, or continuous, in which case a separate clarifier and piping for recycling of settled solids are provided.

The ability of activated sludge basins to detoxify bleached kraft mill effluents was analyzed over a five month period.(84) Two pilot-scale activated sludge systems (8-hr and 24-hr detention) were operated with and without surge equalization. Raw wastewater BOD5 varied from 108 to 509 mg/l. The raw wastewater was consistently toxic. Reported raw wastewater median survival times (MST) to fish ranged from 7 to 1,440 minutes. Total resin and fatty acid concentrations in the raw wastewater ranged from 2 to 8 mg/l.

Mean BOD5 removals for the 8-hr and 24-hr activated sludge systems with a 12-hr surge equalization basin achieved an average of 72 percent and 76 percent BOD5 removal, respectively. Effluent BOD5 concentrations for the 24-hr system ranged from 5 mg/l to 263 mg/l, with a mean of 59 mg/l. The 24-hr system detoxified the effluent 87 percent of the time. Final effluent BOD5 concentrations for the 8-hr system ranged from 14 to 270 mg/l with a mean of 70 mg/l. The effluent was detoxified 89 percent of the time.(84)

The 24-hr activated sludge system, when operated without equalization, was subjected to more vigorous mixing plus the addition of 10 mg/l alum. Under these conditions, an average of 90 percent BOD5 removal was obtained and detoxification was achieved 100 percent of the time. The 8-hr activated sludge system, when operated without surge equalization, was also subjected to more vigorous mixing with no addition of alum. Under these conditions, an average of 84 percent BOD5 removal was obtained, although detoxification was attained only 55 percent of the time.(84) The authors concluded that equalization did not affect BOD5 removal efficiency, but improved the detoxification efficiency by 15 to 30 percent. Addition of alum to the activated sludge system appeared to reduce toxicity. The authors speculated that the mechanism of toxicity removal was a chemical reaction.(84) Failures to detoxify were attributed in some instances to hydraulic shocks, black liquor spills, or inadequate treatment system operation, although in many instances no cause could be determined.(84)

The pure oxygen activated sludge process uses oxygen, rather than air, to stimulate biological activity. This scheme allows for a lesser detention time and a lower aeration power requirement than for the conventional activated sludge process; however, additional power is required for oxygen generation which may result in a net increased power requirement. Waste secondary solids volumes that must be dewatered and disposed of are similar to those produced by air activated sludge systems.

Field test data by Union Carbide Corp. confirms that the oxygen activated sludge process is capable of achieving final effluent BOD5 concentrations on the order of 15 to 30 mg/l when applied to unbleached kraft wastes.(94) Effluent TSS after clarification was generally in the range of 40 to 60 mg/l.(94) A summary of pilot-scale information is presented in Table VII-7.

A sulfite-newsprint effluent was treated using an oxygen activated sludge pilot plant facility over an 11 month period. BOD5 reductions during this time were over 90 percent.(95) Final BOD5 and TSS concentrations ranged from 23 to 42 mg/l and 61 to 111 mg/l, respectively.(95) The effluent from the oxygen activated sludge system was found to be acutely toxic.(95) Total resin acids before and after oxygen activated sludge treatment were 25 and 6 mg/l, respectively.(95) Ammonia was found at levels on the order of 50 mg/l. The treated effluent was air stripped to determine if ammonia was the major cause of the high toxicity. Although air stripping reduced the ammonia concentration to less than 1 mg/l and the total resin acid concentration to 1 mg/l, the effluent remained acutely toxic.

Easty studied two examples of pure oxygen activated sludge systems: one treating integrated bleached kraft wastewater and the other treating unbleached kraft pulp mill wastewater.(83) Both significantly reduced all identified pollutants. The pollutants evaluated included resin and fatty acids, their chlorinated derivatives, and chloroform. The first system incorporated an oxygen activated sludge basin with hydraulic detention of 190 minutes and a sludge recycle rate of 35 percent. The pH was maintained between 6.[illegible] and 7.5. It was determined from Easty's data that 43 to 92 percent of identified pollutants were removed, with the chlorinated resin acids exhibiting relatively low removal efficiencies. This is consistent with observed biodegradabilities of bleach plant derivatives.(96)

The second oxygen activated sludge system was operated at a detention time of 3.7 hours and a mixed liquor suspended solids (MLSS) concentration of 2,500 mg/l.(83) Bench-scale alum/polyelectrolyte coagulation followed. The effluent was adjusted to a pH of 5 with alum; 1 mg/l of polyelectrolyte was added. Essentially complete removal of all identified resin and fatty acids was obtained. It should also be noted that initial concentrations in the raw waste were relatively low. Since no data were reported for the oxygen activated sludge system without chemically assisted clarification, the relative effects of each of the two processes on removal efficiencies could not be determined.

The Zurn/Attisholz (Z/A) process is a two-stage activated sludge system. The first stage operates at a DO of less than 1.0 mg/l; the DO level in the second stage is maintained at 4 to 5 mg/l. Nutrient

TABLE VII-7

OXYGEN ACTIVATED SLUDGE TREATABILITY
PILOT SCALE*

duction Process	Retention (Hr)	BOD5 (mg/l) Influent	BOD5 (mg/l) Effluent	TSS (mg/l) Influent	TSS (mg/l) Effluent
:aline-Unbleached	1.3 - 2.2	277 - 464	20 - 41	57 - 86	46 - 61
kaline-Unbleached	1.8 - 3.0	214 - 214	16 - 22	123 - 123	36 - 36
.kaline-Unbleached	2.0 - 2.9	265 - 300	25 - 30	95 - 120	60 - 70

:ource: Technical data supplied by Union Carbide Corp.(94)

and power requirements for the two-stage system are similar to those for the conventional activated sludge process. A total Z/A detention time of four hours may be required to achieve BOD5 and TSS reductions comparable to activated sludge and aerated stabilization basin systems.

Seven full-scale Zurn/Attisholz systems are currently in use at pulp, paper, and paperboard mills in the United States. These installations treat wastewaters from the following types of manufacturing:

Deink(Fine or Tissue)	(5 mills)
Papergrade Sulfite	(1 mill)
Groundwood-Fine Papers	(1 mill)

At most of the mills where the Zurn/Attisholz process is used, final effluent BOD5 and TSS concentrations are attained in the range of 20 to 25 mg/l.(97) At one mill, BOD5 and TSS levels in the range of 5 to 10 mg/l are attained.(97) At another mill, 96 percent BOD5 and 99 percent TSS reductions are attained using the Z/A process.(98)

A pilot study comparing a two-stage to a single-stage activated sludge system has recently been performed. It was concluded that the two-stage system achieved a higher toxicity reduction in treating bleached kraft wastewater than did a single-stage system.(99)(100)

Rotating Biological Contactor (RBC). This system involves a series of discs on a shaft supported above a basin containing wastewater. The discs are 40 to 45 percent submerged in the wastewater and are slowly rotated; a biological slime grows on the disc surfaces. Closely spaced discs with a diameter of 3.7 meters (12 ft) mounted on a 7.6 meter (25 ft) shaft can result in 9,300 square meters (100,000 sq ft) of surface area.

Pilot-scale evaluations of an RBC system treating bleached kraft wastewater with an average influent BOD5 concentration of 235 mg/l have resulted in substantial BOD5 reductions.(101) The degree of removal is related to the hydraulic loading rate, as seen in Table VII-8. Secondary waste solids production reportedly ranged from 0.3 to 0.5 kg of solids per kg of BOD5 removed (0.3 to 0.5 lb of solids per lb of BOD5 removed).(101)

Two pilot plant evaluations reported essentially complete detoxification of board mill, integrated kraft, and magnesium-based sulfite mill effluents.(102) Final effluent BOD5 of 59 mg/l for the kraft mill, 65 mg/l for the board mill, and 338 mg/l for the sulfite mill were reported. Raw wastewater BOD5 levels for these mills were 290 mg/l, 285 mg/l, and 1,300 mg/l, respectively. No TSS data were reported.(102) This pilot plant work indicates good toxicity and BOD5 reduction capabilities. However, to date, mill-scale systems in the United States treating pulp mill wastewater have encountered operating difficulties.

TABLE VII-8

PILOT RBC FINAL EFFLUENT QUALITY FOR
BLEACHED KRAFT WASTEWATER*

Hydraulic Loading Rate (gpd/sq ft)	70% of Time Final Effluent BOD5 Less Than (mg/l)	90% of Time Final Effluent BOD5 Less Than (mg/l)
3	70	90
2	30	45
1	22	39

Note: Raw Effluent BOD5 = 235 mg/l.

*Source: Gillespie, W.J., D.W. Marshall, and A.M. Springer, A Pilot Scale Evaluation of Rotating Biological Surface Treatment of Pulp and Paper Wastes, NCASI, Technical Bulletin No. 278, 1974.(101)

Anaerobic Contact Filter. This process involves the use of a basin filled with crushed rock or other media. Wastewater is passed through the media at a temperature of 32° to 35°C (90° to 95° F) under anaerobic conditions; detention times on the order of three days are common. Steam stripping, nutrient addition, neutralization, and dilution of waste liquor with wash water may be required as pretreatments.

A laboratory study of the process showed that 80 to 88 percent BOD_5 removal from sulfite wastewaters to levels as low as 34 mg/l have been achieved.(103) The major advantage of the process is a low solids production rate of 0.08 kilograms of solids per kilogram of BOD_5 removed (0.08 pounds of solids per pound BOD_5 removed). This results because methane gas is the by-product of anaerobic digestin rather than biological solids. The author concludes that the cost for the anaerobic process was approximately the same as that for aerated stabilization.(103)

Partial detoxification of sulfite mill wastewater was obtained in a laboratory-scale system.(88) The anaerobic contact filter altered the LC-50 from 4.5 percent to 7.8 percent for rainbow trout. No specific data concerning specific toxic pollutants were reported.

Impact of Temperature Variations. All biological treatment systems are affected by temperature, particularly by large and/or sudden temperature changes. The effect of temperature variations on aerobic biological systems has been demonstrated in both theory and practice; therefore, temperature is of importance in the choice of design and operation of treatment systems. McKinney has stated that all processes of growth are dependent on chemical reactions and the rates of these reactions are influenced by environmental conditions, including temperature.(104) The discussion below presents theoretical and operating data on temperature variations and their effects. Included is an evaluation of the effect of temperature on biological treatment system performance as measured by BOD_5 and TSS removals.

BOD_5 is a measurement of the dissolved oxygen used by microorganisms for the biochemical oxidation of organic matter in a wastewater. Biochemical oxidation occurs in two stages: a first stage in which the carbonaceous (organic) matter is oxidized and a second stage in which nitrification occurs. The oxidation of the carbonaceous matter results from the biological activity of bacteria and other organisms in the wastewater. For a stated set of environmental conditions, growth of microorganisms will follow a predictable and reproducible pattern closely allied to the amount of organic matter present in a wastewater, measured as BOD_5, and its rate of utilization by the microorganisms present.(105)

The heterogeneous population of bacteria found in aerobic biological systems treating wastewaters at temperatures such as those resulting from the production of pulp, paper, and paperboard encompass three classified groupings of bacteria: psychrophilic, mesophilic, and thermophilic organisms.

Seasonal wastewater temperature variations change the specific growth rate of the heterogeneous population, and to a lesser extent, the relative distribution of the types of bacteria comprising the population. McKinney (104) has depicted the rate of growth for mesophilic organisms with the maximum rate occurring in the rangeof 35° to 40°C (95° to 104°F). Similar growth rate/temperature distributions exist for both psychrophilic and thermophilic organisms, with the optimal growth rate occurring in the range of 10° to 15°C (50° to 59°F) for psychrophiles, and 60° to 65°C (140° to 149°F) for thermophiles.(96) However, the predominant group found at all normal operating temperatures in aerobic systems are the mesophiles.(106)

A number of studies have been conducted to quantify various aspects of microbial growth, temperature, and BOD_5 reduction. Degradation of organic matter in pulp, paper, and paperboard wastewaters has been evaluated and found to proceed at rates similar to other wastewater sources.(107)(108)(109)(110)(111)(112)(113)(114)

Soluble BOD_5 reduction by microorganisms approximates first-order kinetics.(106) A temperature decrease of 10°C (18°F) from the optimal temperature would necessitate an increase in detention or reaction time of approximately 35 percent to attain the same effluent BOD_5 level as that attained at the optimal temperature. Conversely, an increase in temperature of 10°C (18°F) would theoretically shorten the detention time by 25 percent to attain the same effluent BOD_5 level.

The above concept is of substantial practical importance in treatment system design, since flexiblity in design allows treatment systems to sustain efficient operation over a wide range of conditions (i.e., increasing microbial (solids) recirculation rates will increase waste/microbe contact time when microbial activity is reduced in colder temperatures). Additional studies relate the specific effects of changes in temperature on BOD_5 and suspended solids reduction to performance for specific systems.(115)(116)

Ammonia Removal Through Nitrification. One method of ammonia removal is through single-stage nitrification in a biological treatment system. Nitrification is the process where specific bacteria, Nitrosommanas and Nitrobacter, convert ammonia to nitrite nitrogen and then to nitrate nitrogen.

Biological treatment systems presently employed at mills in the pulp, paper, and paperboard industry are generally designed and operated for oxidation of organic material (i.e., BOD_5 reduction). It is possible, however, to design and operate these systems to accomplish BOD_5 and ammonia reduction in a single step or in a series of steps. Nitrifying organisms exhibit a very slow growth rate in comparison to organic assimilation and are very sensitive to environmental conditions and growth inhibitors, such as toxic organic wastes and heavy metals. Growth rates and, thus, nitrification rates, are profoundly influenced by such environmental factors as pH, temperature, and dissolved oxygen (DO) concentrations. Since the nitrifiers are autotrophic, inorganic carbon sources such as carbon ioxide, carbonates, and bicarbonate have a large influence on icrobial growth rates.(117)

erobic nitrifiers require relatively large quantities of molecular oxygen to complete the oxidation of ammonia. The theoretical oxygen requirements, based on the biochemical equations of nitrification, have been determined to be 4.57 kg O_2 required/kg ammonia nitrified (4.57 lb O_2 required/lb ammonia nitrified). Generally, this oxygen demand may be satisfied by atmospheric molecular oxygen furnished through conventional aeration techniques. However, since the nitrifiers are autotrophic and obtain their carbon requirements from such compounds as carbon dioxide and bicarbonates, the oxygen contained in these compounds may also be available for metabolism. Thus, depending on the alkalinity of the wastewater, the actual oxygen which must be furnished by aeration equipment may be lower than the theoretical 4.57 ratio. Discounting the ammonia required for BOD_5 removal, the nitrifiers will also utilize a fraction of the available nitrogen for synthesis of cellular components. This ammonia demand is estimated to be equivalent to 0.7 to 0.9 oxygen equivalents; therefore, the theoretical oxygen ratio of 4.57 would be reduced to about 4.1 kg O_2/kg ammonia nitrified (4.1 lb O_2/lb ammonia nitrified).(118)

Since the nitrifiers have slower growth rates, a biological system designed for nitrification requires a longer detention time (i.e., longer sludge age). Insufficient nitrification will result unless the sludge wastage rate is lowered to accommodate the nitrifier requirements. Therefore, the wastage rate is usually controlled to maintain a sufficient sludge age in the system to accomplish nitrification. Published data for municipal wastes indicate that a sludge age greater than four days in the activated sludge process is adequate for 90 percent nitrification at 20°C (68°F).(118) Laboratory experiments conducted on pulp and paper wastewaters (weak black liquor) with influent ammonia and BOD_5 concentrations of 264 mg/l and 511 mg/l indicate that a sludge age of approximately 14 days is required for conversion of 90 percent of the ammonia to nitrate. (117)

In the absence of severe inhibitors, a single-stage activated sludge system can be properly designed to achieve BOD_5 removal and nitrification in a single aeration basin. Available literature indicates that 90 percent ammonia removal can be achieved through nitrification.(107)(112)(119)(120)(121)(122) In low strength wastes, ammonia removal to levels of less than 10 mg/l is achieveable depending on the variability of the influent ammonia concentration. (118)

Chemically Assisted Clarification

Dissolved and colloidal particles in treated effluents are not readily removed from solution by simple settling. These particles can be agglomerated by the addition of chemical coagulants. Coagulants in common use include lime, alum, ferric chloride, ferric sulfate, and magnesia. Detailed discussions of the chemistry of coagulants are available.(123)

Rebhum and others suggest that the most efficient method of pulp and paper mill effluent flocculation is a solids-contact type clarifier.(124) Ives suggests a theory for the operation of solids-contact clarifiers that considers their integrated role as flocculators, fluidized beds, and phase separators.(125) His theory suggests that the criterion for good performance is the dimensionless product of velocity gradient, time, and floc concentration. He suggests that model floc blanket studies can be meaningful for full-scale operation provided that the concentration of floc in the blanket and the blanket depth are the same in both model and prototype.(125)

Ives also suggests a number of design considerations for solids-contact clarifiers. For floc particles to form a blanket in a circular tank, the upflow velocity of the water must be equal to the hindered settling velocity of floc suspension. It is important that the floc removed from the blanket balance the rate of floc formation. The clarifier should be symmetrical; the inlet flow should be uniformly dispersed and the collection at the outlet should also be uniform. The clear water zone should have a minimum depth equal to half the spacing between collection troughs.

Upon floc formation, settling is accomplished in a quiescent zone. The clarification process results in waste solids that must be collected, dewatered, and disposed of. The quantity, settleability, and dewaterablity of the waste solids depend largely on the coagulant employed. In some cases the coagulant can be recovered from the waste solids and reused.

Case studies of full, pilot, and laboratory-scale chemical clarification systems are discussed in the following sections.

Case Studies-Full Scale Systems. Several full-scale, chemically assisted clarification systems have been constructed in the pulp, paper, and paperboard industry and in other industrial point source categories. Data on the capability of full-scale systems to remove conventional and nonconventional pollutants are presented below.

Conventional Pollutants - Recent experience with full-scale alum-assisted clarification of biologically treated kraft mill effluent suggests that final effluent levels of 15 mg/l each of BOD_5 and TSS can be achieved. The desired alum dosage to attain these levels can be expected to vary depending on the chemistry of the wastewater to be treated. The optimum chemical dosage is dependent on pH.

Chemical clarification following activated sludge is currently being employed at a groundwood (chemi-mechanical) mill. According to data provided by mill personnel, alum is added at a dosage of about 150 mg/l to bring the pH to an optimum of 6.1. Polyelectrolyte is also added at a rate of 0.9 to 1.0 mg/l to improve flocculation.

Neutralization using NaOH is practiced prior to final discharge to bring the pH within acceptable discharge limits. The chemical/biological solids are recycled through the activated sludge system with no observed adverse effects on biological organisms. Average reported results for 12 months of sampling data (as supplied by mill personnel) show a raw wastewater to final effluent BOD5 reduction of 426 mg/l to 12 mg/l and TSS reduction of 186 mg/l to 12 mg/l.

Treatment system performance at the mill was evaluated as part of a study conducted for the EPA.(126) Data obtained over 22 months shows average final effluent BOD_5 and TSS concentrations of 13 and 11 mg/l, respectively. As part of this study, four full-scale chemically assisted clarification systems in other industries were evaluated. Alum coagulation at a canned soup and juice plant reduced final effluent BOD_5 concentrations from 20 mg/l to 11 mg/l and TSS levels from 65 mg/l to 22 mg/l. Twenty-five mg/l of alum plus 0.5 mg/l polyelectrolyte are added to the biologically treated wastewater to achieve these final effluent levels. Treatment plant performance was evaluated at a winery where biological treatment followed by chemically assisted clarification was installed. Final effluent levels of 39.6 mg/l BOD_5 and 15.2 mg/l TSS from a raw wastewater of 2,368 mg/l BOD_5 and 4,069 mg/l TSS were achieved. The influent wastewater concentrations to the clarification process were not reported. The chemical dosage was 10 to 15 mg/l of polymer.(126) A detailed summary of the results of the study of full-scale systems is presented in Table VII-9.(126)

In October, 1979, operation of a full-scale chemically assisted clarification system treating effluent from an aerated stabilization basin at a Northeast bleached kraft mill began. This plant was designed and constructed after completion of extensive pilot-scale studies. The purpose of the pilot plant was to demonstrate that proposed water quality limitations could be met through the use of chemically assisted clarification. After demonstrating that it was possible to meet the proposed levels, studies were conducted to optimize chemical dosages. The testing conducted showed that the alum dosage could be reduced significantly by the addition of acid for pH control, while still attaining substantial TSS removal. In the pilot-scale study, it was shown that total alkalinity, a measure of a system's buffering capacity, was a reliable indication of wastewater variations and treatability. Through this study, it was shown that there is a direct relationship between total alkalinity and alum demand. High alkalinity (up to 500 mg/l) caused by the discharge of black liquor or lime mud results in high alum demands. Therefore, a substantial portion of alum dosage can be used as an expensive and ineffective means of reducing alkalinity (pH) to the effective pH point (5-6) for optimum coagulation. The use of acid to assist in pH optimization can mean substantial cost savings and reduction in the alum dosage rate required to effect coagulation. In one instance, use of concentrated sulfuric acid for pH reduction, reduced alum demand by 45 percent. Acid addition was also effective in reducing alum dosage for wastewaters with a low alkalinity (approximately 175 mg/l).(127)

SUMMARY OF CHEMICALLY ASSISTED CLARIFICATION
TECHNOLOGY PERFORMANCE DATA

Major Industrial Category	Industrial Plant & Location	Subcategory or Products	Description of Biological Treatment	Average of Period - Clarifier Influent BOD_5	Influent TSS	Effluent BOD_5	Effluent TSS	Maximum Day Clarifier Effluent BOD_5	Maximum Day Clarifier Effluent TSS	Maximum 30 Consecutive Days Average Clarifier Effluent BOD_5	Maximum 30 Consecutive Days Average Clarifier Effluent TSS	Recent Removals Across Clarifier BOD_5	Recent Removals Across Clarifier TSS	Surface Overflow Rates and Detention Time	Chemicals Added and Dosage Rate Average	NPDES Permit Average Maximum Day BOD_5	NPDES Permit TSS	Average of Period Plant Influent Flow	Plant Influent BOD_5	Plant Influent TSS
Pulp and Paper	[illegible]	Bleached Kraft Mech.	Aerated stabilization basin 21.8 # BOD_5/1000 cu ft./D Hydraulic detention time - 8 days at 2.25 MGD Nitrogen & phosphorous added	Average of 12 months of daily data N.D.	Average of 12 months of daily data 1295.7 lb/day	Average of 12 months of daily data 1,3 .7 lb/day	Average of 12 months of daily data 172.8 lb/day	506.4 lb/day	1502.6 lb/day	Based on 12 months of daily data 201.1 lb/day	Based on 12 months of daily data 250.5 lb/day	Based on annual average Based on mean of 30 consecutive day averages N.D.	87%	For annual ave. flow of 1.6 MGD 369 gal/day/ sq.ft. For max.day flow of 2.8 -641 gal/day/ sq.ft.	Alum - Silica -	30 Day average 275 lb/D ORDER NPDES NO. 1 July '75	30 Day average 400 lb/D No. 74-69 CA0004821 effective	MGD 1.95 average of 12 months of daily data	475.7 mg/l average of 12 months of daily data	1.6 [illegible] 1660 gal average of 12 months of daily data
				average of 10 months of daily data 315.5 lb/day	average of 10 months of daily data 737.7 lb/day	average of 10 months of daily data 1,8.2 lb/day	average of 10 months of daily data 177.2 lb/day	473.3 lb/day	1400.2 lb/day	Based on 10 months of daily data 239.7 lb/day	Based on 10 months of daily data 257.9 lb/day	Based on annual average (10 months) 29% Based on mean of 30 consecutive day averages 35%	76% 76%	For annual average flow of 1.9 MGD - 432 gal/day /sq.ft. For max.day flow of 2.5 MGD - 564 gal/ sq.ft.	Alum - 150 mg/l average Polymer 0.5 mg/l average	Average flow of 2.2 mgd. Max. day 550 lb/D 30 mg/l	Max. Day 600 lb/D 40 mg/l	1.9 MGD Average of 10 months of daily data	N.D.	1.7 [illegible] 1660 gal Average of 10 months of daily data
Synthetic Fiber Manufacturer	6-11	Dacron (R) and ethylene glycol	Activated sludge (extended aeration) F/M - 0.05 to 0.1 lb. BOD_5 applied/lb MLSS MLSS - 2000-2500 mg/l	Data not provided		Average of 4 quarterly averages with chemicals 113.3 lb/D	Average of 4 quarterly averages with chemicals 203.8 lb/D	Data not provided.		Data not provided.		Data not available for calculations		For average period flow- 2.097 MGD 220 gal/D/ sq.ft. 7 hours detention	Polymer only cationic 0-10 mg/l Average 8 mg/l	Daily average 750 lb/D NPDES NO. 31 Dec. 73 to 31 Dec. 76 Ave. flow 2.5 MGD	Daily average 1040 lb/D NC0000663	Data not provided.		
For "Alfa" System			Hydraulic detention time 10 hours at 2 MGD Nitrogen & phosphorous added	Data not provided		Average of 4 quarterly averages without chemicals 151 lb/D	Average of 4 quarterly averages without chemicals 665.3 lb/D	Data not provided.		Data not provided.		Data not available for calculations		For average period flow- 1.67 MGD 176 gal/D/ sq.ft. 7 hours detention	None added	Daily maximum 100 lb/D	Daily maximum 2060 lb/D	Data not provided.		
Canned Foods	6-12	canned soup, juices	2 stage trickling filter filter followed by aerated lagoon with 5 days detention with sub-surface static aeration 18" diameter x 12 feet long.	Annual average June '75 to May '76 20 mg/l No back up data provided	Annual average June '75 to May '76 65 mg/l No back up data provided	Figures provided without back up data 11 mg/l Annual average June '75 to May '76	22 mg/l Annual average June '75 to May '76	Data not provided		Data not provided.		No back up data provided for calculation		558 gal/day/ sq. ft. @ 4.3 MGD = 3.5 hours detention time	Campbell soup had no record of when chemicals were added or not added Alum can be added at lagoon effluent weir @ 25 mg/l Polymer added at flow splitting box before clarifiers 0.5 mg/l	Daily average - 45 mg/l TSS Daily maximum - 90 mg/l TSS Daily average - 30 mg/l BOD_5 Daily maximum - 75 mg/l BOD_5 NO. 0221 *AD		4.3 MGD average Number provided, no back-up data provided	473 mg/l average Number provided, no back-up data provided	364 mg/l average Number provided, no back-up data provided
Wine Making	[illegible]	Wine	Activated sludge 18 & 16 BOD/1000 cu.ft. F/M = 0.07 MLSS = 4069 Detention Time = 8 days 0.176 MGD Phosphorous and nitrogen added	Average of period from April 26, 1976 to July 31, 1976 2168 mg/l	Average of period from April 26, 1976 to July 31, 1976 4069 mg/l	Average of period from April 26, 1976 to July 31, 1976 39.6 mg/l Data after post aeration and chlorination	15.2 mg/l	Data after post aeration and chlorination 70 mg/l	36 mg/l for period April 26, 1976 to July 31, 1976	Data not available		Average of period from April 26, 1976 to July 31, 1976 N/A	99.6%	At average flow 0.177 MGD 140 gal/D shift 11.5 hours	Polymer at 10-15 mg/l Testing period for proper dosage	Process Season - Daily average - 30 mg/l - BOD_5 Daily maximum 50 mg/l - BOD_5 Daily average - 20 mg/l - TSS Daily maximum - 50 mg/l TSS		0.177 MGD Average of period April 26, 1976 to July 31, 1976 Caution - does not include the the pressing season which is the season of highest loading	2168 mg/l	215.5 mg/l

Table VII-10 summarizes effluent quality of the full-scale system since startup; this system has been operated at an approximate alum dosage rate of 350 mg/l without acid addition. Recent correspondence with a mill representative indicated that, with acid addition, this dosage rate could be reduced to 150 mg/l.(128) However, this lower dosage rate has not been confirmed by long-term operation.

Scott, et al. (129) reported on a cellulose mill located on the shore of Lake Baikal in the USSR. The mill currently produces 200,000 kkg (220,000 tons) of tire cord cellulose and 11,000 kkg (12,100 tons) of kraft pulp per year. Average water usage is 1,000 kl/kkg (240 kgal/t). The mill has strong and weak wastewater collection and treatment systems. The average BOD5 for the weak wastewater system is 100 mg/l, while the strong wastewater BOD5 is 400 mg/l. Only 20 percent of the total wastewater flow is included in the strong wastewater system. Each stream receives preliminary treatment consisting of neutralization to pH 7.0, nutrient addition, and aerated equalization. Effluent from equalization is discharged to separate aeration and clarification basins. These basins provide biological treatment using a conventional activated sludge operation. Aeration is followed by secondary clarification. Suspended solids are settled and 50 percent of the sludge is returned to the aeration process. Waste sludge is discharged to lagoons. The separate streams are combined after clarification and are treated for color and suspended solids removal in reactor clarifiers with 250 to 300 mg/l of alum and 1 to 2 mg/l of polyacrylamide flocculant, a nonionic polymer. The clarifiers have an overflow rate of approximately 20.4 cu m per day/sq m (500 gpd/sq ft).

Chemical clarification overflow is discharged to a sand filtration system. The sand beds are 2.9 m (9.6 ft) deep with the media arranged in five layers.(130) The sand size varies from 1.3 mm (0.05 in) at the top to 33 mm (1.3 in) at the bottom. The filter is loaded at 0.11 cu m per minute/sq m (2.7 gpm/sq ft). Effluent from sand filtration flows to a settling basin and then to an aeration basin; both basins are operated in series and provide a seven hour detention time.

The effluent quality attained is as follows:

Parameter	Raw Waste	Final Effluent
BOD5 (mg/l)	300	2
Suspended Solids (mg/l)	60	5
pH	-	6.8 - 7.0

Individual treatment units are not monitored for specific pollutant parameters.

<u>Nonconventional Pollutants</u>. The development of coagulation processes for color removal has been traced by many investigators. Investigators concluded that lime precipitation was a coagulation process for color removal which afforded the possibility of chemical

TABLE VII-10

FINAL EFFLUENT QUALITY OF A CHEMICALLY ASSISTED CLARIFICATION SYSTEM TREATING BLEACHED KRAFT WASTEWATER

Date	BOD (mg/l)		TSS (mg/l)	
	Average for Month	Maximum Day	Average for Month	Maximum Day
September 1979	11	21	87	254
October 1979	8	12	40	92
November 1979	9	18	28	47
December 1979	21	83	21	56
January 1980	8	16	28	36
February 1980	7	14	31	68
March 1980	13	46	44	113
April 1980	9	16	32	96
May 1980	11	22	38	80

recovery utilizing existing mill equipment. Based on the results of this early work, research continued towards development of a lime precipitation process. The overriding problem in this work continued to be the difficulty of dewatering the lime-organic sludge. Specific studies were conducted for resolving the sludge problem with limited success.(131)(132)

Continuing efforts to improve the dewatering of the lime sludge led to consideration of using large dosages of lime for color reduction. It was believed that a large quantity of rapidly draining materials would reduce the effect of the organic matter on dewatering. This thinking led to the development and patenting of the "massive lime" process by the National Council for Air and Stream Improvement. In this process, the mill's total process lime is slaked and reacted with a highly colored effluent stream, usually the caustic extraction effluent. The lime sludge is then settled, dewatered, and used for causticizing green liquor. During the causticizing process, the color bodies are dissolved in the white liquor and eventually burned in the recovery furnace. Although the massive lime process had been demonstrated as an effective color removal system, the process was not taken beyond the pilot stage for several years.

The first installation of the massive lime color system was operated at a mill in Springhill, Louisianna. The 33.4 liter per sec (530 gpm) demonstration plant was used to treat the bleach plant caustic extraction and unbleached stock decker wastewaters. These streams contributed 60 to 75 percent of total mill color. In the process, the lime slurry dosage was 20,000 mg/l.

The demonstration plant at Springhill was first tested using 100 percent bleach plant caustic extraction effluent. Various amounts of unbleached decker effluent were then added until 100 percent decker effluent was treated. Color removal ranged from 90 to 97 percent with an average of 94 to 95 percent (133). Organic carbon removal ranged from 55 to 75 percent and generally increased with higher colored effluent. The values reported are shown in Table VII-11. BOD_5 removals of 25 to 45 percent were reported with lower values found during treatment of most highly-colored effluent. The net effect of the process was estimated as a 72 percent reduction of total mill color.

The massive lime process, as developed, required lime dosages c approximately 20,000 mg/l. Because of this, only a relatively sma: effluent stream could be treated with the quantity of lime used f causticizing green liquor. Additionally, this process requir modifications to the recovery system. These restrictions led to t development of an alternative process employing "minimum lir treatment. Lime dosages of 1,000 to 2,000 mg/l are common to t process.(134) Previous EPA documents have reported data on full-sc minimum lime treatment systems.(134) Two systems treating unbleac kraft and NSSC effluents are known to be operating. Color levels 1,200 to 2,000 color units are reported to be 80 to 90 percent rem with lime dosages of 1,000 to 1,500 mg/l. A full-scale sy

TABLE VII-11

COLOR AND ORGANIC CARBON REMOVAL AFTER APPLICATION OF MASSIVE LIME TREATMENT*

Composition of Treated Effluent: Bleach Plant Caustic Extraction Stage Effluent (%)	Kraft Decker Effluent (%)	Effluent Color (APHA Color Units): Before Treatment	Effluent Color (APHA Color Units): After Treatment	Color Removal (%)	Organic Carbon (mg/l): Before Treatment	Organic Carbon (mg/l): After Treatment	Organic Carbon Removal (%)
100	0	21,546	1,265	94.2	1,446	373	74.2
67	33	14,325	745	94.8	1,016	253	75.1
60	40	12,125	594	95.1	905	248	72.6
50	50	10,043	451	95.5	798	245	69.3
33	67	6,612	331	95.0	569	183	67.8
20	80	4,660	298	93.6	450	173	61.6
0	100[1]	1,640[1]	140[1]	91.5[1]	270[1]	120[1]	55.6[1]
0	100[2]	900[2]	234[2]	74.0[2]	268[2]	126[2]	53.0[2]

[1] Very little paper mill white water reuse for decker pulp washing or as make-up water.

[2] Practically all water used in decker system was white water from paper mill.

*Oswalt, J.L., and J.G. Lund Jr., Color Removal from Kraft Pulp Mill Effluents by Massive Lime Treatment, EPA Project 12040 DYD, 1973.(133)

treating the first caustic extract of a bleached kraft mill has been shut down. When operating, lime dosages of 1,500 to 3,000 mg/l were used to remove 90 percent of a color load that ranged from 8,000 to 10,000 color units.(134)

Case Studies-Pilot and Laboratory Scale. Several laboratory and pilot-scale studies of the application of chemically assisted clarification to treat pulp, paper, and paperboard wastewaters have been conducted. Available data on the capability of this technology to remove conventional and nonconventional pollutants based on laboratory and pilot-scale studies are presented below.

Conventional Pollutants - As part of a study of various solids reduction techniques, Great Southern Paper Co. supported a pilot-scale study of chemically assisted clarification.(135). Great Southern operates an integrated unbleached kraft mill. Treatment consists of primary clarification and aerated stabilization followed by a holding pond. The average suspended solids in the discharge from the holding pond were 65 mg/l for the period January 1, 1973 to December 31, 1974. In tests on this wastewater, 70 to 100 mg/l of alum at a pH of 4.5 provided optimum coagulation. Three alum dosages were tested. At the optimum dosages, the removals after 24 hours of settling ranged from 83 to 86 percent. Influent TSS of the sample tested was 78 mg/l. Effluent TSS concentrations ranged from 11 to 13 mg/l.

In a recent EPA-sponsored laboratory study, alum, ferric chloride, and lime in combination with five polymers were evaluated in further treatment of biological effluents from four pulp and paper mills.(136) Of the three chemical coagulants, it is reported that alum provided the most consistent flocculation at minimum dosages, while lime was the least effective of the three. However, the study provides inconclusive results in determining the optimum chemical to be used or the optimum chemical dosage for removal of TSS from biologically-treated effluents. These inconclusive findings are the result of a number of factors, including (a) the lack of determination of an optimum pH to effect removal of TSS, (b) the lack of consideration of higher chemical dosages when performing laboratory tests even though data for some mills indicated that better removal of TSS was possible with higher chemical dosage (a dosage of 240 mg/l was the maximum considered for alum and ferric chloride, while 200 mg/l was the maximum dosage used for lime), (c) the testing of effluent from one mill where the TSS concentration was 4 mg/l prior to the addition of chemicals, and (d) the elimination of data based simply on a visual determination of proper flocculation characteristics.

Laboratory data on alum dosage rates for chemically assisted clarification have been submitted to the Agency in comments on the contractor's draft report.(137) Data submitted for bleached and unbleached kraft wastewaters indicate that significant removals of suspended solids occur at alum dosages in the range of 100 to 350 mg/l.(138)(139)(140) For wastewaters discharged in the manufacture of dissolving sulfite pulp, effluent BOD_5 and TSS data were submitted for dosage rates of 250 mg/l; however, it was stated that dosages required to achieve effluent TSS concentrations on the order of 15 mg/l would be in the range of 250 to 500 mg/l.(141) Subsequent to the comment period, the NCASI has assembled jar test data for several process types and submitted it to the Agency.(142) Data for chemical pulping subcategories indicate that alum dosages in the range of 50 to 700 mg/l will effect significant removals of TSS. The average dosage rate for all chemical pulping wastewaters was 282 mg/l. Data submitted for the groundwood, deink, and nonintegrated-fine papers subcategories indicate that dosages in the range of 100 to 200 mg/l will significantly reduce effluent TSS.

Toxic and Nonconventional Pollutants - As part of an EPA-sponsored study, biologically-treated effluent from a kraft mill was further treated using alum precipitation technology on a laboratory-scale.(83) Existing full-scale treatment at the mill consisted of a primary clarifier, an aerated stabilization basin, and a polishing pond. Twenty-four hour composite samples of the polishing pond effluent were taken on three separate days. The samples were adjusted to a pH of 4.6 with alum; four drops of polymer per liter of sample were added. The results are summarized below:

	Polishing Pond Effluent Range (mg/l)	Alum-Treated Effluent Range (mg/l)
Total Resin and Fatty Acids	2.82 - 3.75	Undetected
Total Chlorinated Derivatives	0.43 - 0.45	Undetected - 0.04
Chloroform	0.025 - 0.032	0.018 - 0.022
BOD5	43.0 - 51.0	0 - 14.0

Other researchers have investigated modifications of chemically assisted clarification technology using lime. This research has concentrated primarily on color removal. Investigations have included the use of alternative coagulants in combination with lime. Olthof and Eckenfelder reported on the use of ferric sulfate, lime, and alum to reduce effluent color at two bleached kraft mills and one unbleached kraft paperboard mill.(143)(144) Their results, as shown in Table VII-12, provide both an optimum pH and optimum dosage for each case. All three coagulants were able to achieve a reduction in color from 1,000 to 3,000 platinum-cobalt (Pt-Co) units to 125 to 300 Pt-Co units. Note that the dosage required for color reduction is higher than that generally applied for BOD5 and TSS reduction only.

Olthof and Eckenfelder concluded that ferric sulfate used for color removal of pulp, paper, and paperboard mill wastewaters can be an attractive alternative to lime treatment. This conclusion was drawn from the fact that the required optimum dosage of ferric sulfate was 25 to 33 percent that of the optimum lime dosage. In addition, the effluent quality which results from use of ferric sulfate was better than that resulting from lime. Lime treatment results in a high pH and a great deal of calcium in solution. Common practice is to use an additional treatment step, recarbonation, which reduces the pH prior to biological treatment and allows for recovery of calcium as $CaCO_3$.

TABLE VII-12

COLOR REDUCTIONS ACHIEVED AFTER APPLICATION OF CHEMICALLY ASSISTED CLARIFICATION WITH FERRIC SULFATE, ALUM, AND LIME*

	Ferric Sulfate				Alum				Lime			
Mill Type	Optimum Dosage (mg/l)	Color Reduction (%)	Final Color Value (Pt-Co.Units**)	Optimum pH	Optimum Dosage (mg/l)	Color Reduction (%)	Final Color Value (Pt-Co.Units**)	Optimum pH	Optimum Dosage (mg/l)	Color Reduction (%)	Final Color Value (Pt-Co.Units**)	Optimum pH
Bleached Kraft	500	92	250	3.5-4.5	400	92	200	4-5	1,500	92	300	12.-12.5
Bleached Kraft	275	91	125	3.5-4.5	250	93	100	4-5	1,000	85	200	12.-12.5
Unbleached Kraft Paperboard	250	95	150	4.5-5.5	250	91	100	5-6	1,000	85	150	12.-12.5

*Sources: Olthof, M.G., "Color Removal From Textile and Pulp and Paper Wastewaters by Coagulation," Vanderbilt University, PhD Thesis, 1975.(143)
Olthof, M.G. and Eckenfelder, W.W., Jr., "Laboratory Study of Color Removal from Pulp and Paper Wasewaters by Coagulation," TAPPI, Vol. 57, No. 8, August 1974.(144)

**Platinum-Cobalt Units

The use of ferric sulfate and alum prior to biological treatment does not require recarbonation and may not require neutralization. Berov studied the need for neutralization of kraft mill effluents which were treated with alum for color removal.(145) He concluded that if the chemically treated process effluent pH did not fall below 5.8, neutralization was not needed prior to biological treatment.

Dugal, Church, Leekley, and Swanson performed laboratory studies on color reduction with a combined ferric chloride and lime treatment system.(146) This study sought to establish conditions for improving the lime treatment systems by using multivalent ions with the lime for color precipitation. Earlier investigations of the lime precipitation treatment system removal demonstrated 85 to 90 percent removal of color; it was determined that the remaining color bodies had an apparent average molecular weight of less than 400. Preliminary studies with multivalent ions and lime showed almost total color removal.

Tests were run in the laboratory on the decker filtrate and caustic extraction discharge from International Paper Company's mill at Springhill, Louisiana. Various salts such as barium chloride, ferric chloride, magnesium hydroxide, and zinc chloride were used in the initial experiments. Based on data from these initial experiments, ferric chloride was selected for further analysis. In general, it was determined that trivalent ions are more effective color-removing agents than divalent ions. Table VII-13 presents a summary of the results.(146)

Twenty-four experiments were run using ferric chloride and/or lime at various concentrations. Color removal up to 98.7 percent was attained and it was concluded that a synergistic effect between lime and ferric chloride existed. Table VII-14 shows the results of these 24 experiments.(146)

Another flocculation and precipitation process is in full-scale operation in Japan; it is also being investigated through laboratory studies in Sweden. The process involves using iron salts and lime to obtain color removals in the range of 85 to 95 percent.(147) Chlorination and caustic extraction stage effluents are treated. Metallic iron is first dissolved in the chlorination stage effluent. Retention times of 1.5 to 2 hours and temperatures near 50°C (122°F) are needed to dissolve a sufficient amount of the metallic iron. The resulting solution is then combined with the caustic extract and the pH adjusted within the range of 9 to 10 with lime. No chemical dosages were listed for the lime required or the amount of metallic iron consumed.

Vincent studied the decolorization of biologically treated pulp and paper mill effluents by lime and lime - magnesia additions.(148) Laboratory-scale studies were conducted on effluents from three kraft mills, one sulfite mill, and one NSSC mill. All except one of the kraft mill effluents had been treated in a biological system before chemical treatment. Separate testing with lime and magnesia showed

TABLE VII-13

COMPARISON OF TREATMENT EFFICIENCIES ON KRAFT EFFLUENTS BY THE APPLICATION OF CHEMICALLY ASSISTED CLARIFICATION USING DIVALENT IONS OR TRIVALENT IONS*

Salt Concentration (mg/l)	Decker Filtrate Final pH	Decker Filtrate Color Removal (%)	Caustic Extract Final pH	Caustic Extract Color Removal (%)
$Mg(OH)_2$				
0	7.2	--	8.2	--
100	7.4	0	8.4	0
200	7.5	2.5	8.7	6.8
250	7.8	5.0	8.9	11.4
300	8.0	2.5	9.0	11.4
350	8.0	2.5	9.0	11.4
400	8.1	7.5	9.1	12.0
600	8.0	7.5	9.2	22.8
$ZnCl_2$				
0	7.2	--	8.1	--
100	6.9	2.5	6.9	0
200	6.5	5.0	6.7	3.9
250	6.5	7.5	6.7	3.9
300	6.4	12.5	6.7	13.6
350	6.3	17.5[a]	6.7	13.4
400	6.2	22.5	6.7	22.9
600	6.0	45.4	6.7	44.0
$BaCl_2$				
0	7.2	--	7.1	--
100	7.3	5.0	6.9	0
200	7.2	16.7	6.5	0
250	7.1	21.7	6.5	0
300	7.0	23.3	6.6	1.3
350	6.9	26.7	6.8	4.1
400	6.7	28.3	6.9	1.1
600	6.4	41.2	7.0	23.7
800	6.2	42.5	7.1	35.9
1000	5.7	61.2	7.1	45.2
$Ca(OH)_2$				
0	--	--	8.6	--
100	--	--	10.3	20.0
200	--	--	11.3	22.5
250	--	--	11.6	22.5
300	--	--	11.7	25.0
350	--	--	11.8	32.5
400	--	--	11.9	62.5
600	--	--	12.1	72.5

Salt Concentration (mg/l)	Decker Filtrate Final pH	Decker Filtrate Color Removal (%)	Caustic Extract Final pH	Caustic Extract Color Removal (%)
Alum ($Al_2(SO_4)_3$ $18H_2O$)				
0	7.2	--	7.9	--
100	7.3	59.1	6.5	7.7
200	5.1	87.1	4.8	63.1
250	4.7	90.9	4.4	95.2
300	4.6	88.1	4.3	94.6
350	4.5	88.2	4.2	85.2
400	4.5	88.2	4.3	84.6
600	4.5	86.8	4.1	86.5
$FeCl_3$-pH unadjusted				
0	7.2	--	6.7	--
100	5.8	27.3	6.1	0
200	5.0	75.5	5.6	24.4
250	4.1	76.4	5.1	26.9
300	3.8	77.3	4.8	51.3
350	3.7	77.3	4.4	74.8
400	3.4	75.5	4.1	91.7
600	3.1	76.4	3.8	90.7
$FeCl_3$-pH adjusted				
0	7.2	--	6.7	--
100	8.2	0	8.4	0.6
200	8.7	21.1	8.9	67.4
250	8.3	12.6	8.7	83.1
300	8.5	38.9	9.1	97.2
350	8.9	58.3	8.6	97.3
400	8.9	50.9	8.1	97.3
600	8.8	72.5	7.8	97.4

[a]Calculated Value.

*Source: Dugal, H.S., Church, J.O., Leekley, R.M., and Swanson, J.W., "Color Removal in a Ferric Chloride-Lime System," TAPPI Vol. 59, No. 9, September 1976.(146)

TABLE VII-14

LIME TREATMENT OF BLEACHED KRAFT CAUSTIC EXTRACT IN THE PRESENCE OF METAL ION[a]*

$FeCl_3$ (mg/l)	Lime (mg/l)	Sludge Volume[b] (ml)	Final pH	Color Removal (%)	TOC Removal (%)	BOD Removal (%)
0	1000	6.2	11.58	81.4	66.6	6.5
25	1000	8.2	11.50	81.7	66.0	4.3
50	1000	8.2	11.42	85.7	71.0	0.0
100	1000	8.5	11.42	90.0	78.0	12.8
200	1000	13.3	11.49	91.4	76.4	23.5
300	1000	14.4	11.50	91.6	74.3	27.7
500	1000	22.0	11.40	95.8	81.0	36.2
800	1000	30.1	11.32	95.5	83.2	40.5
0	2000	6.2	11.79	87.2	68.6	23.5
25	2000	7.0	11.70	88.0	75.4	23.5
50	2000	7.3	11.70	89.5	73.0	25.5
100	2000	9.7	11.70	91.8	75.2	29.8
200	2000	14.1	11.70	93.6	79.6	34.0
300	2000	19.1	11.71	95.2	81.6	36.2
500	2000	33.5	11.78	96.8	86.0	44.7
800	2000	62.0	11.73	97.5	87.3	51.0
0	18,000	8.9	11.98	93.4	80.4	32.0
25	18,000	8.7	11.99	94.9	79.5	32.0
50	18,000	9.0	11.98	95.0	77.6	38.4
100	18,000	9.4	12.00	95.9	81.7	36.2
200	18,000	11.2	12.01	96.3	84.0	36.2
300	18,000	12.2	12.01	97.3	81.5	46.8
500	18,000	14.3	12.01	98.2	87.7	46.8
800	18,000	16.8	12.00	98.7	88.7	51.0

[a]Untreated caustic extract had a pH of 8.83, a color of 4400 units, a TOC of 220 mg/liter, and a BOD of 47 mg/liter.

[b]Total volume of kraft bleach caustic extract after lime and $FeCl_3$ addition was 100 ml. Sludge volumes were measured after a 15-minute settling time.

*Source: Dugal, H.S., Church, J.O., Leekley, R.M. and Swanson, J.W., "Color Removal in a Ferric Chloride-Lime System," TAPPI, Vol. 59, No. 9, September 1976.(146)

that, with the addition of 1,000 mg/l of lime, approximately 90 percent of the color was removed. Magnesia alone proved to be ineffective at moderate doses; 4,000 mg/l were required to obtain approximately 50 percent color reduction. Therefore, it was concluded that the use of magnesia alone could not be justified.

The use of magnesium hydroxide in combination with lime was highly effective. The magnesium was added as a soluble salt prior to the lime slurry. A dosage of 50 to 100 mg/l of magnesia prior to the addition of 500 mg/l of lime gave the same color removal as the addition of 1,000 mg/l of lime alone. Additionally, sludge production was less with the lime - magnesia process. Table VII-15 shows some typical results of the lime - magnesia process for removing color, BOD, COD, and phosphate for the five mills. Recovery techniques were suggested but none were investigated in connection with this study. This would indicate additional testing would have to be done to prove the feasibility of this lime - magnesia recovery process before attempting it on a larger scale. An evaluation concluded that the system is costly, but the benefits might favor its use.

Filtration

This process refers to granular bed (rather than membrane) filtration. The granular material may be sand, or coal, diatomaceous earth, and/or garnet in combination with sand. The various media, grain sizes, and bed depths may be varied for optimal results. It is common to vary grain sizes, with the larger sizes at the top of the filter bed, to improve TSS removal and to extend filter run time between backwashings. The addition of a proper chemical flocculant prior to filtration can further improve performance.

Filtration technology was evaluated as part of a recent study conducted for the EPA.(126) Results obtained during this study of nine pulp, paper, and paperboard and other industrial facilities where filtration is used are shown in Tables VII-16 and VII-17. Also summarized in the tables are the results of pertinent published results from other filtration studies. Table VII-16 summarizes those systems where coagulants were not used prior to filtration, while Table VII-17 addresses those where coagulants were employed.

At those facilities where chemical coagulants were not utilized, final effluent levels of TSS ranging from 5.9 to 35 mg/l were achieved across the filter; TSS reductions ranged from 45 to 79 percent. Those where coagulants were used prior to filtration achieved final effluent TSS levels ranging from 5.0 to 27.5 mg/l with removals of 52 to 85 percent. At the paperboard mill employing single medium sand filtration without chemical addition, an effluent TSS level of 7 mg/l was attained.

An EPA-sponsored laboratory study evaluated the efficiency of sand filtration of four pulp and paper mill effluents.(136) A flow rate of 0.20 cu m per minute/sq m (5 gpm/ft2) was used and the results are shown in Table VII-18. As seen, in one of the two cases where

TABLE VII-15

REMOVAL OF BOD, COD, AND PHOSPHATE FROM CHEMICAL PULPING WASTEWATERS AT SELECTED LIME - MAGNESIA LEVELS*

		Treatment		Before Treatment				After Treatment				Removal			
Mill	Effluent	CaO (mg/l)	MgO (mg/l)	Color	BOD[1]	COD[2]	Phosphate[3]	Color	BOD	COD	Phosphate	Color	BOD	COD	Phosphate
A	Kraft (combined effluent, 80% bleached) biological treatment	500	100	2,570	-	420 (560)	1.05	137	16	100	<0.01	94.7	-	76	99.0
B	Kraft (high BOD stream, unbleached) no biological treatment	500	100	1,070	130	340 (560)	0.7	78	105	580 1,310	0.07	92.7	19	-	90.0
C	Kraft (combined effluent) biological treatment	500	100	2,620	60	500 (720)	3.0	185	30	100	0.06	92.9	50	80	98.0
D	Sulfite (NH_3 base, combined effluent) biological treatment	2,000	400	1,790	60	2,430 (1,300)	0.8	298	67	460	0.07	83.4	-	81	91.3
E	NSSC (combined effluent) biological treatment	6,000	3,000	36,300	525	8,640 (4,960)	31.5	12,800	320	1,040	0.80	64.7	39	88	97.5

[1] BOD determined after filtration through Reeve-Angel glass filter papers and subsequent adjustment to pH 7.

[2] COD determined after filtration through Reeve-Angel glass filter papers. Bracketed values are for unfiltered effluents.

[3] Phosphate analysis (values in mg/l of P) determined by modified ascorbic acid method.

*Source: Vincent, D.L., Colour Removal From Biologically Treated Pulp and Paper Mill Effluents, Distributed by CPAR Secretariat, Canadian Forestry Service, Department of the Environment Ottawa, Ontario, as CPAR Report 210-1, March 31, 1974.(148)

TABLE VII-16

TSS REDUCTION CAPABILITIES AND RELATED FACTORS FOR THE FILTRATION TECHNOLOGY WHEN NO CHEMICALS ARE USED

Source of Data	Source of Wastewater	Biological Treatment Process Description	Filter Influent TSS Concentration & Source of Data	Filter Influent TSS Size - Percent < microns*	Hydraulic Loading	Filter Media: No. of Media, Depth, U.S., E.S., Type of Filtration	TSS Filter Effluent	Percent Removal Across Filter, Avg for Period of Data
A-1	Oil refinery	Activated sludge: F/M - 0.3 MLSS - 1200 mg/l Capacity of 2 basins - ND Detention time - ND Average flow - 4.37 MGD DO min - 1.0 mg/l	10.8 mg/l average of daily data for June 1976	<1.25 - 19.0 <2.5 - 57.0 <5.0 - 89.8	at 4.37 MGD & 3 filters - 3.2 gpm/sq ft	2 media: coal, sand - coal - 18", 0.6 to 0.8 mm sand - 9" 0.4 to 0.5 mm in depth filtration	5.9 mg/l, average of daily data June 1976	TSS - 45%
A-2	Oil refinery	Activated sludge: 10 lb BOD/ 1000 cu ft, F/M - ND MLSS - ND, DO min - Detention time - 24 hrs @ 1.15 MGD, Mechanical Aeration Average flow - 1.15 MGD	ND	<1.25 - 28.5 <2.5 - 76.3 <5.0 - 89.2	at 1.15 MGD & 3 filters - 2.4 gpm/sq ft	2 media: coal, sand - coal - 24"; UC - ND ES - ND. sand - 12" UC - ND, ES - ND In depth filtration	ND	ND
A-3	Oil refinery	Activated sludge: complete mix, F/M - .02 lb BOD/lb MLVSS, MLSS - 3,500 mg/l DO min - Detention time - 12 hrs @ 23 MGD, Mechanical Aeration Average flow - 19.11 MGD	ND	<1.25 - 53.0 <2.5 - 88.3 <5.0 - 97.5	at 19.11 MGD & 9 filters - 3.5 gpm/sq ft	2 media: coal, sand - coal - 24"; UC - ND ES - ND. sand - 12" UC - ND, ES - ND in depth filtration	11 mg/l, average of 12 monthly averages	ND
A-7	Paperboard products	Activated sludge - complete mix, 20.5 lb BOD/1000 cu ft F/M - .5, MLSS - 3,500 mg/l DO min - Detention time - 12 hrs @ 2 MGD Average flow - 2.0 MGD	ND	<1.25 - 69.3 <2.5 - 91.6 <5.0 - 95.8	at 2.0 MGD & 3 filters - 3.7 gpm/sq ft	1 media: sand sand - 6'0"; ES - 2-3 mm, Sp.Gr. - 2.7	7.0 mg/l, average of 5 monthly averages Feb 76-June 76	ND
A-4	Manmade fiber processing	Activated sludge - 18 lb BOD/ 1000 cu ft, F/M - MLSS - DO min - Detention time - 48 hrs @ 0.5 MGD Average flow - 2.8 MGD	49.5 mg/l average of 2 monthly averages Does not include old aeration system flow	ND	at 2.83 MGD & 3 filters - 2.15 gpm/sq ft	4 medias: 2 coal, sand, garnet - Coal - 12" Sp.Gr.-1.45 UC & ES - ND Coal - 12" Sp.Gr.-1.5 UC & ES - ND Sand - 9", UC & ES - ND Garnet - 3", UC & ES - ND	16.2 mg/l, average of 2 monthly averages	67%, includes post aeration
Literature Greater Southern Paper Co. Cedar Springs, GA, Pilot study	kraft neutral - sulfite semichemical pulp & paper	Aerated stabilization basin:	average for 3 runs - 68 mg/l	ND	2 gpm/sq ft	ND	average for 3 runs - 35 mg/l	50% Reported by Researchers
Literature Clinton Corn Processing Co. Clinton, IA	food processing	Activated sludge complete mix F/M - MLSS - DO min - Detention time - Average flow -		ND				77%, Nov. 25, 1974 to Feb. 16, 1975
Literature Welch Foods Brocton, NY	grape processing	Activated sludge	season average - 28 mg/l	ND			8.4 mg/l season average	70%, season average
Literature New Brunswick Research & Productivity Council Pilot Plant	pulp mill	Aerated lagoon - lb BOD/1000 cu ft - DO min - Detention time - 12.5 days Total aeration only 8 days Average flow -	40 mg/l grab samples	<5u - 60% between 5 & 10u 30%	2.4 to 3.6 gpm/sq ft	3 media - 7" of coarse coal, 3" medium sand - ES - .56, UC - 1.32 5" of coarse sand - ES - 1.42, UC - 1.34	21 mg/l	50%

*Based on one grab sample.

ND = No Data

TABLE VII-17

TSS REDUCTION CAPABILITIES AND RELATED FACTORS FOR THE FILTRATION TECHNOLOGY WHEN CHEMICALS ARE USED

Source of Data	Type of Wastewater	Biological Treatment Process Description	Filter Influent TSS Concentration and Source of Data	Filter Influent TSS Size - Percent <Microns *	Hydraulic Loading Gal. Per Min. Per Square Foot	Filter Media # of Medias, Depth U.C., E.S., Type of Filtration	TSS in Filter Effluent	Percent Removal Across Filter Ave. for Period of Data	Chemicals Added
A-9	Carpet Yarn Dyeing	Activated sludge - extended air 16 lb BOD_5/1000 cu. ft. FM - MLSS - 3500-4000 mg/l DO Min - Detention time - 48 hrs. @ 0.5 MGD Average flow - 0.44 MGD	N.D	1.25u - 46.4 2.5u - 78.5 5.0u - 93.5	at 0.44 MGD and 2 filters 1.9 gpm/sq. ft.	3 Media -coal,sand,garnet Coal - 18" UC - N.D. ES - N.D. Sand - 10" UC - N.D. ES - N.D. Garnet - 9" UC - N.D. ES - N.D.	20.2 mg/l Average of 11 monthly averages	N.D.	Alum - 80-120 mg/l polymer - 1.5 mg/l Added just ahead of secondary clarifier
A-4	Man-made fiber processing	Activated sludge - 18 lb BOD_5/1000 cu. ft. F/M - MLSS - DO Min. - Detention time - 26 hrs @ 2.83 MGD Average flow - 2.83 MGD	53.2 mg/l Average of 10 monthly averages - from grab samples Does not include old auction system flow	1.25u - 29.7 2.5u - 83.9 5.0u - 91.1	at 2.83 MGD and 3 filters 2.15 gpm/sq.ft.	4 Media - 2 coal,sand,garnet Coal - 12" Sp Gr - 1.45 UC & ES - N.D. Coal - 12" Sp.Gr. - 1.5 UC & ES - N.D. Sand - 9" UC & ES - N.D. Garnet - 3" UC & ES - N.D.	7.7 mg/l Average of 10 monthly averages following: post- aeration & activated carbon	85%	Alum - 10 mg/l Polymer - 0.1 mg/l Activated Carbon - 35 mg/l added in-line just ahead filters
A-5	Reconstituted tobacco	Activated sludge - 15.1 lb BOD_5/1000 cu.ft. F/M - .07 MLSS - 3500 mg/l DO Min - Detention time - 120 hrs @ 1.0 MGD Average flow - 1.0 MGD	N.D.	1.25 u - 21.2 2.5u - 52.9 5.0u - 78.2	at 1.0 MGD and 3 filters 46 gpm/sq.ft.	2 Media - coal,sand Coal - 24" ES - 1.2 mm UC - N.D. Sand - 19" ES - 0.5 mm UC - N.D.	N.D.	N.D.	Polymer added at overflow weir of aeration basin Dosage - N.D.
A-8	Paper towels and napkins	Aerated stabilization basin	143 mg/l Average of 6 monthly averages of one grab sample	1.25u - 49.8 2.5u - 84.2 5.0u - 90.4	4 gpm/sq.ft.	2 Medias-coal,sand Coal - 18" ES - 1.5 mm Sand - 12" ES - 0.7 mm	N.D.	N.D.	N.D.
A-6	Pet food manufacturer	Activated sludge - complete mix N.D. F/M - N.D MLSS - 3500 mg/l DO Min - Detention time - 90 hrs @ 0.3 MGD Mechanical aeration Average flow - 0.3 MGD	N.D.	1.25u - 30 2.5u - 55 5.0u - 85	@ .3 MGD and 3 filters 2 gpm/sq.ft.	2 Media- coal, sand Coal - 36" Sand - 24"	6.5 mg/l average for April 1976	N.D.	Cationic polymer added to flow just ahead of clarifier Dosage - N.D.
Literature - Cellulose mill on Lake Baikal USSR Full scale installation	Tire cord cellulose and kraft paper pulp	Activated sludge - MLSS - 2500 mg/l DO Min - Detention time - 8 hrs @ 76 MGD Average flow -	N.D.	N.D.	2.7 gpm/sq.ft	1 Media - sand ES - 1.2 - 2.0 mm 9.6 ft deep	5 mg/l following 6 hr. settling lagoon & 6 hr aerated lagoon	N.D.	Alum - 30 mg/l Polymer - 1.0 mg/l nonionic ahead of chemical clarifier
Literature Amoco Oil Yorktown, VA.	Oil refining	Aerated lagoon - F/M - MLSS - DO. Min. - Detention time - Average flow -	57.6 mg/l	N.D.	3.6 gpm/sq.ft.	3 Media-coal,sand,garnet Coal - 22" Sand - 11" Illmenite - 7"	27.5 mg/l Average of 5 period averages June 1971 to December 1972	52%	Alum - just ahead filters

Note: *Based on [illegible] analysis
[illegible]

TABLE VII-18

SAND FILTRATION RESULTS*

Mill No.	Initial TSS (mg/l)	TSS Removal (%)	
		w/chemicals	w/o chemicals
1	110	64	14
2	5.5		36
3	70	71	68
5	60		23

*Peterson, R.R. and Graham, J.L., "Post Biological Solids Characterization and Removal from Pulp Mill Effluents," EPA-600/2-79-037, 1979.(136)

coagulation was not employed prior to filtration, substantially better results were obtained than when coagulants were added. It was explained by the authors that natural coagulation, that may have occurred during shipment of samples, could have affected the results.

Activated Carbon Adsorption

Currently, there are two basic approaches for the use of activated carbon: a) use in a tertiary sequence following primary and biological processes and b) use in a "physical-chemical" treatment in which raw wastewater is treated in a primary clarifier with or without chemical coagulants prior to carbon adsorption.

The tertiary approach involves the reduction of biodegradable organics prior to discharge to the carbon system. This provides for longer carbon life. In a physical-chemical treatment mode, biodegradable and refractory organics are removed solely through adsorption on the activated carbon. Activated carbon can achieve high removals of dissolved and colloidal pollutants in water and wastewater. When applied to a well treated biological effluent, it is capable of reducing BOD5 to less than 2.0 mg/l.(149)

The primary means by which removal occurs is by surface adsorption. The key to the carbon adsorption process is the extremely large surface area of the carbon, typically 3.54 to 9.92 square meters per gram (sq m/g) (17,300 to 48,500 sq ft/lb).(150)

Activated carbon will not remove certain low molecular weight organic substances, particularly methanol, a common constituent of pulping effluents.(151) Additionally, carbon columns do a relatively poor job of removing turbidity and associated organic matter.(152) Some highly polar organic molecules such as carbohydrates also will not be removed through the application of activated carbon treatment.(152)(153) However, most of these materials are biodegradable and, therefore, should not be present in appreciable quantities in a well bio-oxidized effluent.

Activated carbon may be employed in several forms including: a) granular, b) powdered, and c) fine. The ultimate adsorption capacities for each may be similar.(154) The optimal carbon form for a given application should be determined by laboratory and/or pilot testing. Each of the three forms of carbon listed above is discussed below.

Granular Activated Carbon. Granular activated carbon has been used for many years at municipalities and industrial facilities to purify potable and process water. In recent years, it has also been used for removal of organics in wastewater.(155)

Granular activated carbon (GAC) treatment usually consists of one or more trains of carbon columns or beds, including one or more columns per train. The flow scheme may be down through a column, up through a packed carbon bed, or up through an expanded carbon bed. The optimum column configuration, flow scheme, and carbon requirements can best be determined through field testing. Design aspects for various systems are readily available in the literature.(150)

It is economically advantageous in most granular activated carbon applications to regenerate the exhausted carbon. Controlled heating in a multiple-hearth furnace is currently the best procedure for removing adsorbed organics from activated carbon. Typically, the regeneration sequence is as follows:

- o Pump exhausted carbon in a water slurry to the regeneration system for dewatering.
- o After dewatering, feed the carbon to a furnace at 816° to 927°C (1,500° to 1,700°F) where the adsorbed organics and other impurities are oxidized and volatized.
- o Quench the regenerated carbon in water.
- o Wash the carbon to remove fines; hydraulically transport the regenerated carbon to storage.
- o Scrub the furnace off-gases and return the scrubber water for treatment.

The West Wastewater Treatment Plant at Fitchburg, Massachusetts treats combined papermill and sanitary wastes at a 57,000 cu m/day (15 mgd) chemical coagulation/carbon adsorption facility.(156) Approximately 90 percent of the flow originates from three papermills, with the remaining 10 percent originating from municipal sanitary wastewater. The industrial wastewater undergoes 5 minutes of rapid mixing and 30 minutes of flocculation prior to mixing with the chlorinated sanitary wastewater. The combined waste is then settled after lime and alum addition. The wastewater is then pumped to twelve downflow pressure carbon filters. Initial operation of the system has resulted in a 96 percent suspended solids reduction and a 39 percent BOD_5 reduction in the pretreatment system. The granular activated carbon filters initially yielded total reductions of suspended solids and BOD_5 of 99 and 97 percent, respectively. Final effluent concentrations were reported as 5.0 mg/l BOD_5 and 7.0 mg/l TSS. No data have been reported concerning toxicity or toxic pollutant removal/ reduction from the plant.

Since the plant was started up in late 1975, it has been plagued with a number of mechanical and operational problems. As a result, the system has been unable to achieve the removal capabilities predicted after initial operation. The plant was designed to produce an effluent quality of 8 mg/l of BOD_5 and TSS on a monthly average. The pretreatment facility has consistently yielded a 55 percent BOD_5 reduction and 95 percent TSS reduction. The carbon filters have provided 55 percent BOD_5 reduction and 70 percent TSS reduction of the remaining pollutants after pretreatment. Overall, the system is anticipated to achieve 80 percent BOD5 reduction and 98 percent TSS reduction once the steady state conditions are met.(157)

Pilot testing by Beak Consultants, Ltd., with laboratory analysis confirmed by B.C. Research, indicates that approximately 80 percent of each of the following resin and fatty acids were removed from raw bleached kraft effluents by application of granular carbon adsorption: pimaric, isopimaric, abietic, dehydroabietic, oleic, linoleic, and linolenic.(158) Initial total resin acid and fatty acid concentrations were 10.6 and 3.9 mg/l as reported by Beak Consultants, Ltd. and 12.6 and 2.2 mg/l as reported by B.C. Research. Total resin acid and total fatty acid concentrations in the treated effluent were 1.49 and 2.4 mg/l as reported by Beak Consultants, Ltd. and 2.25 and 0.4 mg/l as reported by B.C. Research. A contact time of 7.5 minutes with a carbon exhaustion rate of 0.6 to 0.7 kg per 1,000 liters (5.0 to 6.0 lb per 1,000 gallons) was employed in the study. Detoxification of the raw woodroom wastewater was successful. However, the authors report that the carbon system did not detoxify whole mill effluent during a simulated black liquor spill, even with a contact time of 30 minutes.

It is noteworthy that the carbon exhaustion rate for BOD5 removal was 20 times shorter than that for toxicity removal. These results imply that a) carbon life may be significantly increased if competing organics are removed prior to carbon adsorption and b) the carbon adsorption capacity for resin and fatty acids is greater than that for other biodegradable organics.

Several researchers have considered the reuse of wastewaters following carbon adsorption treatment. Kimura showed that the use of activated carbon following biological treatment and sand filtration was capable of completely detoxifying kraft board mill wastewater. In this application, the final effluent was recycled as process water.(159)

According to Smith and Berger, pulp and papermill wastewater suitable for reuse can be obtained using granular carbon without a biological oxidation step, particularly if the raw wastewater exhibits a BOD5 of 200 to 300 mg/l.(160) Color due to refractory organic compounds contained in pulping effluents can also be reduced by such treatment. Table VII-19 presents the pilot plant results obtained by the authors.

Condensate streams account for only about 2 to 10 percent of total wastewater flow, but contribute significantly higher proportions of toxicity and BOD5 when discharged. Tests by Hasen and Burgess showed that 70 to 75 percent of the BOD5, COD, and TOC in kraft evaporator condensate could be removed using 0.46 kg of carbon per 1,000 liters (3.8 lb of carbon per 1,000 gallons) of wastewater.(153) Treatment with granular activated carbon reduced the effluent toxicity effects on bay mussels by a factor of up to 17. The toxicity removal efficiency was found to be much more dependent on contact time than were BOD5 and COD removals. For example, a contact time of 30 minutes and carbon dosage of 40.1 g/l (0.334 lb/gal) resulted in an 80 percent COD reduction to 186 mg/l and an 85 percent larval survival in a 10

TABLE VII-19

RESULTS OF PILOT-SCALE GRANULAR ACTIVATED CARBON TREATMENT OF UNBLEACHED KRAFT MILL WASTE*

Parameter	Desired Range	Raw Waste	After Lime Treatment	After Carbon Treatment	Removal (%)
pH	6.8-7.3	7.8	11.9	10.5	--
Color (Pt-Co Units)	0-5	1,280	28	0	100
BOD5 (mg/l)	0-2	265	82	12	95.5
COD (mg/l)	0-8	517	320	209	59.6
Suspended Solids (mg/l)	0-5	128	115	74	42.2
Total Solids (mg/l)	50-250	1,210	1,285	1,205	0.4

Note: Columns were loaded at 3.6-4.0 gpm/sq ft

*Smith, D.R. and Berger, H.F., "Wastewater Renovation," TAPPI, Vol. 51, No. 10, October 1968.(160)

percent condensate solution. However, an extended contact time of 19 hours under otherwise similar conditions resulted in an increase to only 82 percent COD reduction or 163 mg/l, while larval survival in 10 percent solution increased to essentially 100 percent.

Weber and Morris found that the adsorption capacity of granular activated carbon increased with a decrease in pH.(161) The effect on the rate of adsorption with changes in temperature was not well defined.

Powdered Activated Carbon. A recent variation of activated carbon technology involves the addition of powdered activated carbon to biological treatment systems. The adsorbant quality of carbon, which has been known for many years, aids in the removal of organic materials in the biological treatment process.(162) This treatment technique also enhances color removal, clarification, system stability, and BOD_5 and COD removal.(163)(164) Results of pilot testing indicate that this type of treatment, when used as a part of the activated sludge process, is a viable alternative to granular carbon systems.(165)(166) Pilot tests have also shown that powdered activated carbon can be used successfully with rotating biological contactors.(167)

At a large chemical manufacturing complex, a full-scale, 151,000 cu m/day (40 mgd), powdered activated carbon system was started up during the spring of 1977.(168) This system includes carbon regeneration. The waste sludge, which contains powdered carbon, is removed from the activated sludge system and is thickened in a gravity thickener. The sludge is then dewatered in a filter press prior to being fed to the regeneration furnace. The regenerated carbon is washed in an acid solution to remove metals as well as other inorganic materials. Fresh carbon is added as make-up to replace the carbon lost in the overflow from the activated sludge process or from the regeneration system.

The process was originally developed because biological treatment alone could not adequately remove the poorly biodegradable organics in the effluent. Data were taken during operation of a laboratory-scale powdered activated carbon unit using a carbon dosage of 160 mg/l and a hydraulic retention of 6.1 hours. Table VII-20 presents the results of this investigation.(168)

It is noteworthy that the estimated capital costs of using powdered activated carbon rather than a conventional activated sludge system at this chemical plant were within 10 percent of each other. Operating cost of the powdered activated carbon system was estimated to be about 25 percent greater than for conventional activated sludge alone.(168)

The powdered activated carbon system described above is a very comlex treatment system that involves operations that may not be required at other installations. The need for a filter press system or acid cleaning system as well as a carbon regeneration furnace must be determined on a case-by-case basis.

TABLE VII-20

POWDERED ACTIVATED CARBON
OPERATING DATA ON A CHEMICAL PLANT WASTEWATER*

Parameter	Raw Effluent	Final Effluent	Percent Removal
Soluble BOD_5 (mg/l)	300	23	92.3
Color (APHA Units)	1,690	310	81.6

*Source: Heath, H.W., Jr., E.I. duPont de Nemours and Company, "Combined Powdered Activated Carbon-Biological (PACT) Treatment of 40 MGD Industrial Waste," presented to Symposium on Industrial Waste Pollution Control, American Chemical Society National Meeting, March 1977.(168)

In a follow-up study on the full-scale powdered activated carbon activated sludge plant, the average results of three months of data are reported in Table VII-21. The carbon dosage was 182 mg/l, while the hydraulic retention was 14.6 hours.(169)

Comparison of the laboratory and full-scale results in Tables VII-19 and VII-20 reflect an increase in BOD_5 and color removal for the full-scale system over that of the laboratory-scale unit.

Fine Activated Carbon. Timpe and Lang have developed a fine activated carbon system for which they have filed a patent application.(154) It is a multi-stage, countercurrent, agitated system with a continuous transfer of both carbon and liquid. One of the major aspects of the fine activated carbon system is the use of an intermediate-size carbon in an attempt to combine the advantages of both powdered and granular carbon while minimizing their limitations. Equipment size and carbon inventory are decreased due to the increased adsorption rate of the intermediate-size carbon.

Timpe and Lang report that the fine activated carbon system showed distinct advantages over the granular activated carbon system. They ran extensive pilot plant tests for treating unbleached kraft mill wastewater with granular and fine activated carbon.(154) Four different treatment processes were investigated using a 110 liter per minute (30 gpm) pilot plant: (a) clarification followed by downflow granular activated carbon columns, (b) lime treatment and clarification followed by granular activated carbon columns, (c) biological oxidation and clarification followed by granular activated carbon columns, and (d) lime treatment and clarification followed by fine activated carbon effluent treatment (subject of a patent application.)

All treatment processes were operated in an attempt to obtain a treated effluent with less than 100 APHA color units and less than 100 mg/l TOC that would allow for reuse of the wastewater in the manufacturing process. The lime-carbon treatment achieved the desired effluent criteria and was considered the most economical of three processes utilizing carbon columns. A relatively small lime dosage of 320 to 600 mg/l CaO without carbonation prior to carbon treatment was reported to be the optimum operating condition for the lime-carbon process. It was determined that the effluent should contain about 80 mg/l Ca for successful optimization of treatment. The required fresh carbon dosage was 0.3 kg of carbon per 1,000 liters treated (2.5 lb per 1,000 gallons treated).

Timpe and Lang reported lower rates of adsorption, resulting in larger projected capital and operating costs, for the biological-carbon and primary carbon processes in treating unbleached kraft mill effluent.(154) The lower rates of adsorption were believed to be caused by coagulation of colloidal color bodies on the carbon surface. They also determined that the use of sand filters prior to the activated carbon was not necessary. The carbon columns operated with a suspended solids concentration of 200 mg/l without problems when

TABLE VII-21

FULL SCALE "PACT" PROCESS RESULTS
ON CHEMICAL PLANT WASTEWATER*

Parameter	Raw Effluent	Final Effluent	Percent Reduction
Soluble BOD_5 (mg/l)	504	15.2	95
Color (APHA Units)	1,416	311	78

*Robertaccio, F.L., "Combined Powdered Activated Carbon - Biological Treatment: Theory and Results," Proceedings of the Open Forum on Management of Petroleum Refinery Wastewaters, June 1977.(169)

backwashed every day or two. Filtration or coagulation of the effluent from the fine activated carbon process was necessary in order to remove the color bodies that formed on the outer surfaces of the activated carbon granules.

It was found that nonadsorptive mechanisms accounted for a significant amount of color and TOC removal in the clarification-carbon process. It was felt that the removals were not due to any biological degradation that might have occurred in the carbon columns. The color colloids were subsequently removed as large settleable solids during the backwashing process.(154) Table VII-22 tabulates the pilot plant results obtained from Timpe and Lang's investigation.

Foam Separation

Foam separation techniques have been evaluated to determine their effectiveness in treating surface active substances (i.e., resin acids) in pulp, paper, and paperboard mill wastewaters. This process involves physical removal of surface active substances through foam generation. In this process, fine air bubbles are introduced into a basin or structure containing the effluent. The air bubbles cause generation of foam in which the surface active compounds are concentrated. Jet air dispersion has been found to be the most efficient technique for foam generation when compared to turbine and helical generation systems.(170)

Several full-scale foam separation facilities have been built for the removal of detergents from municipal wastes.(171)(172) The Los Angeles County Sanitation District system operated a system treating a flow of 45,000 cu m/day (12 mgd) at a seven minute detention. Water reclamation was the primary purpose of the unit, which operated successfully and trouble-free during two years of continuous operation.(173) This system, like other municipal systems, has ceased operation due to regulations that require the use of biodegradable detergents.

A bleached kraft whole mill effluent was analyzed for total resin acid content before and after treatment in a pilot-scale foam separation unit.(173) Two mill effluents were treated in a two hour detention time foam separation pilot unit. The resin acid content in all cases was reduced by between 46 and 66 percent. The range of total resin acid content in the influents and effluents were 2.6 to 5.1 mg/l and 0.1 to 1.0 mg/l, respectively. In all cases the treated effluent was rendered nontoxic to fish.

Pilot studies have been performed using foam separation as a pretreatment prior to the application of activated sludge and aerated stabilization treatment of bleached kraft effluent.(174) These studies have shown the detoxification efficiency of biological treatment to improve from 50 to 85 percent of the time without foam separation to over 90 percent of the time with foam separation.(174)

TABLE VII-22

RESULTS OF PILOT-SCALE ACTIVATED CARBON TREATMENT OF UNBLEACHED KRAFT MILL EFFLUENT*

Description of Carbon Process	Columns Preceded By Biological Oxidation & Clarification			Columns Preceded By Primary Clarification			Columns Preceded By Primary Clarification			Columns Preceded By Lime Treatment & Clarification			FACET System		
	Inf.	Eff.	Removal	Inf.	Eff.	Removal	Inf.	Eff.	Removal	Inf.	Eff.	Removal	Inf.	Eff.	Removal
BOD (mg/l)										26% Removal					
TOC (mg/l)	148	57	61%	220	83	62%	310	121	61%	177	100	44%	158	101	36%
Turbidity (JTU)											5-15				
Color (Pt-Co Units)	740	212	71%	925	185	80%	1160	202	83%	252	76	70%	157	73(a)	
Hydraulic Load (gpm/sq ft)	2.13			1.42			0.71			1.42			--		
Carbon	Granular			Granular			Granular			Granular			Intermediate		
Contact Time (Min)	140									108					
Fresh Carbon Dosage (lb carbon/ 1000 gal.)	8			20.5			28			2.5			3.9		
pH										11.3					

(a)Filtered

*Source: Timpe, W.G. and Lang, E.W., "Activated Carbon Treatment of Unbleached Kraft Effluent for Reuse - Pilot Plant Results," TAPPI Environmental Conference, San Francisco, May 1973.(154)

Microstraining

At two nonintegrated papermills, full-scale coagulation/microstraining facilities are used for treating rag pulp and fine paper effluents.(175)(176) Coagulant usage includes the addition of 1 mg/l of polymer plus the addition of alum or caustic for pH adjustment. Typically, suspended solids and BOD_5 reductions to 10 mg/l and 50 mg/l, respectively, are achieved. When properly operating, treatment approaching that achievable through the application biological treatment has been obtained. It has been observed that upsets caused by such practices as paper machine washup with high alkaline cleaners affect the effectiveness of the technology.(175)

Electrochemical Treatment

Electrochemical treatment technology involves the application of an electrical current to the effluent to convert chloride to chlorate, hypochlorite, and chlorine. The chlorine and hypochlorite can oxidize organic compounds and be reduced again to chloride ions. The process then repeats in a catalytic fashion. The oxidation of organic compounds reduces the BOD_5, color, and toxicity of the effluent. A significant advantage of the process is that no sludge is produced.

Oher found that whole mill bleached kraft effluent could be reduced in color by 80 percent and caustic extract could be reduced in color by more than 90 percent through electrochemical treatment.(177) Similar results were achieved when using a lead dioxide or a graphite anode. The lead dioxide anode required less energy. No toxicity or toxic pollutant data were reported.

In a variation of the process, Barringer Research Ltd. investigated the use of a carbon fiber electrochemical reactor to treat kraft caustic bleach extracts.(178) The high surface to volume ratio of the carbon greatly decreased the reactor volume requirements. At an effluent to water volume ratio of 60 percent (v/v), toxicity was reported to be reduced from 10 percent mortality in 22 hours to zero percent mortality in 96 hours. Color reduction of 90 percent and BOD_5 and COD reductions of 50 percent and 60 percent, respectively, were reported. This process is in full-scale use in the mining industry but no pilot or mill-scale unit has been applied in the pulp, paper, and paperboard industry.(179) The primary drawback of the process is failure of the carbon cell to perform for extended periods.(179)

Another variation to this process involves the use of hydrogen gas bubbles generated in the process to float solids and separate scum. Selivanov found that an electrochemical unit with graphite anodes and stainless st eel cathodes could cause coagulation in kraft white water.(180) Release of hydrogen bubbles in the process caused solids removal by flotation. Total suspended solids were reduced to 2 to 4 mg/l. No toxicity data were reported.

Herer and Wooaard found significant color and TOC reductions in bleachery wastes by application of electrolytic cells using an aluminum anode.(181) Color removals from chlorination and caustic extraction effluents were 92 percent and 99 percent, respectively, while TOC removals were 69 percent and 89 percent, respectively. Specific concentrations, however, were not reported.

Ion Flotation

This process involves the addition of a surfactant ion of opposite charge to the ion to be removed. The combining of these ions results in a precipitate, the colligend. The colligend is removed by passage of air bubbles through the waste and collection of the resulting floating solids.

Many of the chromophoric (color producing) organics in pulp, paper, and paperboard mill wastewaters are negatively charged, making this process suitable for the removal of color. Chan investigated the process on a laboratory scale.(182) A variety of commercial grade cationic surfactants were tested and Aliquat 221 produced by General Mills was found to be very effective. The process removed over 95 percent of the color from bleached kraft effluents. No specific removals of toxicity or toxic pollutants were reported.

Air/Catalytic/Chemical Oxidation

Complete oxidation of organics found in pulp, paper, and paperboard mill wastewaters to carbon dioxide and water is a significant potential advantage of oxidation processes. Partial oxidation coupled with biological treatment may have economic and/or technical advantages over biological treatment alone.

Past studies of oxidative processes have dealt principally with COD or TOC as a measure of performance. Barclay has done a thorough compilation of related studies and found that most were performed with wastewater other than those resulting from the production of pulp, paper, and paperboard.(183) Some tentative conclusions, though, may still be drawn:

- o Complete oxidation with air can occur under extreme temperature and pressure, high intensity irradiation, with air at ambient conditions in the presence of excessive amounts of strong oxidants (O_3, H_2O_2 or ClO_2), or air or oxygen in the presence of catalysts such as certain metal oxides.

- o Sulfite wastes can be partially detoxified by simple air oxidation for a period of seven days.

- o Ozone oxidation achieved only slight detoxification of sulfite wastes after two hours and partial detoxification after eight hours.(183)

- o Major BOD_5 reductions can only be achieved under conditions similar to those required for nearly complete oxidation.

No data specifically relating to toxic pollutant removal were reported.

Steam Stripping

Steam stripping involves the removal of volatiles from concentrated streams. Hough reports that steam stripping at a kraft mill is capable of removing 60 to 85 percent of the BOD_5 from condensate streams.(184) The ability of the process to remove specific pollutants (including toxic and nonconventional pollutants) depends on the relative boiling points of the pollutants with respect to that of water (i.e., the pollutants must be volatile). Resin acids have boiling points in the range of 250°C (482°F) and thus are not readily stripped through application of this process.(185)

Steam stripping was evaluated for its ability to detoxify condensates from sulfite waste liquor evaporators.(186) This stream accounted for 10 percent of the whole mill effluent toxicity and 28 percent of the total BOD_5 load. Toxicity in the condensate stream was attributed to acetic acid, furfural, eugenol, juvabione, and abietic acid. The application of steam stripping had no observable effect on the toxicity of the stream, although the total organic content was reduced.

Steam stripping of kraft mill digester and evaporator condensates was employed on a mill scale for control of total reduced sulfur (TRS) compounds and toxicity.(187) The 96-hour LC-50 of the condensate was altered from 1.4 percent to 2.7 percent. Thus, the stream remained highly toxic, even after steam stripping. The process did remove 97 percent of the TRS compounds. Production process changes such as minimizing condensate volume, installation of spill collection systems, reduction of fresh water use, and conversion to dry debarking along with the application of steam stripping resulted in a nontoxic effluent.

Ultrafiltration

Ultrafiltration utilizes membranes of a specified molecular size to treat wastewater. The process relies on an external pressure (i.e., pumping) to input the driving force to the wastewater as it is transported through the membranes. The size opening for the ultrafiltration membrane depends on the size of the molecules to be removed from the wastewater.

Data are available from Easty for nonconventional pollutant removal from two bleached kraft caustic extraction effluents utilizing two types of ultrafiltration systems.(83) Good removals of epoxystearic acid, dichlorostearic acid, trichloroguaiacol, and tetrachloroguaiacol were obtained in each case. Chlorinated resin acids were effectively removed by one system but not the other.

The first system employed only one spiral wound membrane, with a surface area of 3.7 sq m (40 sq ft). Filtration of suspended solids larger than 10 micrometers (0.004 in) was accomplished prior to ultrafiltration. The system was operated at 28.4 liters per minute (7.5 gpm) and a pH of 11 to 11.5. The system achieved 50 to 80 percent reduction of chlorinated phenolics but only 0 to 15 percent removal of chlorinated resin acids. The lower percent removals of chlorinated resin acids reflect a low initial concentration of these pollutants in the waste.

The second system treated an effluent volume of 12.5 liters per minute (3.3 gpm) using a tubular cellulose acetate membrane with a surface area of 1.1 sq m (12.1 sq ft). The system operated at a pH of 9.5 to 10.5 and inlet and outlet pressures of 15.0 ATM (220 psi) and 6.8 ATM (100 psi), respectively. Filtration of all particles larger than 10 micrometers (0.004 in) was accomplished prior to ultrafiltration. This system removed approximately 80 to 85 percent of all chlorinated resin acids, chlorinated phenolics, and other acids.

Color, lignosulfonate, COD, and solids removals from sulfite liquor after the application of ultrafiltration were studied by Lewell and Williams.(188) Removals on the order of 30 to 50 percent were observed for color, lignosulfonate, COD, and TSS. No toxicity or toxic pollutant data were reported. Costs (1971) were estimated at $5.70/kl ($1.50/kgal) for a 3785 cu m (1.0 mgd) permeate flow. It was concluded that ultrafiltration could not compete economically with lime as a means of removing lignosulfonate, color, COD, and solids.(188)

Reverse Osmosis/Freeze Concentration

Reverse osmosis employs pressure to force a solvent through the membrane against the natural osmotic force. This is the same type of process as ultrafiltration except that the membranes used for reverse osmosis reject lower molecular weight solutes. This means that lower flux rates occur; there is also a need for a higher operating pressure difference across the membrane than those necessary for ultrafiltration.

Reverse osmosis is employed at a Midwest NSSC mill where 270 kkg/day (300 tpd) of corrugating medium are produced. The system allows operation of a closed white water system. Easty reported that the system achieved BOD_5 reductions of approximately 90 percent and removed essentially all resin and fatty acids.(83) The 320 liter per minute (85 gpm) reverse osmosis unit employs 288 modules, each with 1.55 sq m (16.7 sq ft) of area provided by 18 cellulose acetate tubes. The system operates at 41 ATM (600 psi) and 38°C (100 °F). During Easty's testing, the white water feed contained 300 mg/l TSS and 40,000 to 60,000 mg/l total dissolved solids. Initial resin and fatty acid levels were: abietic, 1.5 mg/l; dehydroabietic, 2.62 mg/l; isopimaric, 2.75 mg/l; pimaric, 0.82 mg/l; oleic, 4.86 mg/l; linoleic, 7.23 mg/l; and linolenic, 0.27 mg/l.(83) The maximum removal capacity is not known since final concentrations were below detection limits.

Reverse osmosis can be followed by freeze concentration whereby the effluent is frozen to selectively remove pollutants. Freeze concentration takes advantage of the fact that when most aqueous solutions freeze, the ice crystal is almost 100 percent water. This process was evaluated by Wiley on three bleachery effluents.(189) Reverse osmosis alone resulted in a concentrate stream of roughly 10 percent of the volume of the raw feed. Freeze concentration reduced the concentrate stream volume by a factor of five while essentially all the impurities were retained in the concentrate. Thus the two processes employed in tandem resulted in a concentrate stream consisting of roughly two percent of the original feed volume that contained essentially all of the dissolved solids.(189) It was reported that the purified effluent was of sufficient quality that it could be returned to the process for reuse.(189) Wiley did not investigate final disposal of the concentrate.

Amine Treatment

This treatment is based upon the ability of high molecular weight amines to form organophilic precipitates. These precipitates are separated and redissolved in a small amount of strong alkaline solution (white water). By so doing, the amine is regenerated for use, with no sludge produced.

The Pulp and Paper Research Institute of Canada (PPRIC) conducted a study to determine the optimum process conditions for employing high molecular weight amines for color, BOD_5, and toxicity reductions of bleached kraft mill effluents.(190) While no specific data on toxic or nonconventional pollutants were reported, whole mill bleached kraft effluent remained toxic after application of the treatment in two reported tests. Likewise, acid bleach effluent could not be detoxified. However, alkaline bleaching wastewater was detoxified in three out of four samples at 65 percent dilution. Final effluent concentrations for BOD_5, COD, and color after treatment of bleached kraft whole mill wastewater were 80 to 350 mg/l, 380 to 760 mg/l, and 80 to 450 APHA units, respectively. Reported removals were 10 to 74 percent, 36 to 78 percent, and 94 to 98 percent, respectively, using Kemaminest-1902D in a solvent of Soltrol 170.

Polymeric Resin Treatment

Polymeric resin treatment involves the use of resins in columns to treat wastewater. The process utilizes adsorption and ion exchange mechanisms to remove pollutants from the wastewater. The columns are reactivated after the treatment cycle is completed. Reactivation can be achieved by utilizing an acid or alkaline solution.

The resin adsorption approach is being pursued by three companies: Billerud Uddeholm, Rohm and Haas, and Dow Chemical Company. The Rohm and Haas and the Dow Chemical processes are at the pilot plant stage. The Billerud Uddeholm color removal process has been operated as a full-scale batch process in Skoghall, Sweden, since 1973.

Based on the experience gained through operation of the full-scale system in treating E_1 caustic effluent, the concept has been expanded into treatment of the C_1 and E_1 effluents from the plant. The first full-scale continuous installation will start-up in the fall of 1980 at Skoghall, Sweden. In this system, a full countercurrent wash will be used and the effluent from the E_1 stage will be reused on the C_1 stage washer after color and toxicity removal through the application of resin adsorption.(67)(191)

The pollutants may be removed from the resin by elution with caustic or oxidized white liquor. The eluate at 10 percent concentration is mixed with the weak black liquor to be evaporated and burned in the recovery boiler. The resin is reactivated with the chlorination effluent. As the chlorination stage effluent reactivates the resin, it is simultaneously decolorized and detoxified. The total mill BOD_5 load is reduced by 30 percent and the color load by 90 percent. The flow diagram of this process is shown in Figure VII-33.

The operating costs for the Billerud Uddeholm system are reported as \$3.74 per kkg of production (\$3.40 per ton of production) (1980). The investment cost of an installation for treatment of the effluent from a 310 kkg/day (340 tpd) kraft pulp mill bleach plant is \$4.0 million (1980) including close-up of the bleach plant. The costs will vary depending on wood species, kappa number, and local conditions.(191) These costs are based upon a resin life of one and one-half years.

The Rohm and Haas process involves the use of Amberlite XAD-8 resin to decolorize bleaching effluent after filtration. The resin can be reactivated without the generation of waste sludge. This reactivation may be accomplished by using mill white liquor. In one study, the adsorption capacity of Amberlite XAD-2 resin was compared to Filtrasorb 300 activated carbon. (192) The resin was more effective in removing most aromatic compounds, phthalate esters, and pesticides; carbon was more effective at removing alkenes. Neither adsorbant was effective in removing acidic compounds. The tests involved use of laboratory solutions of 100 organic compounds at an initial concentration of 100 ug/l.

Another study has shown synthetic resin to be capable of removing a higher percentage of COD from biological effluent than carbon. (193) Also, resin treated wastewater quality was improved when further treated with carbon, although the reverse was not true. The economics of this system could prove favorable since resin may be regenerated in situ. Thus, total regeneration costs may be more economical than for either system alone since carbon life could be significantly extended.

Elimination of toxic constituents from bleached kraft effluents has been achieved with Amberlite XAD-2 resin.(194)(195) Wilson and Chappel have reported that treatment with Amberlite XAD-2 resin resulted in a nontoxic semi-chemical mill effluent. (196)

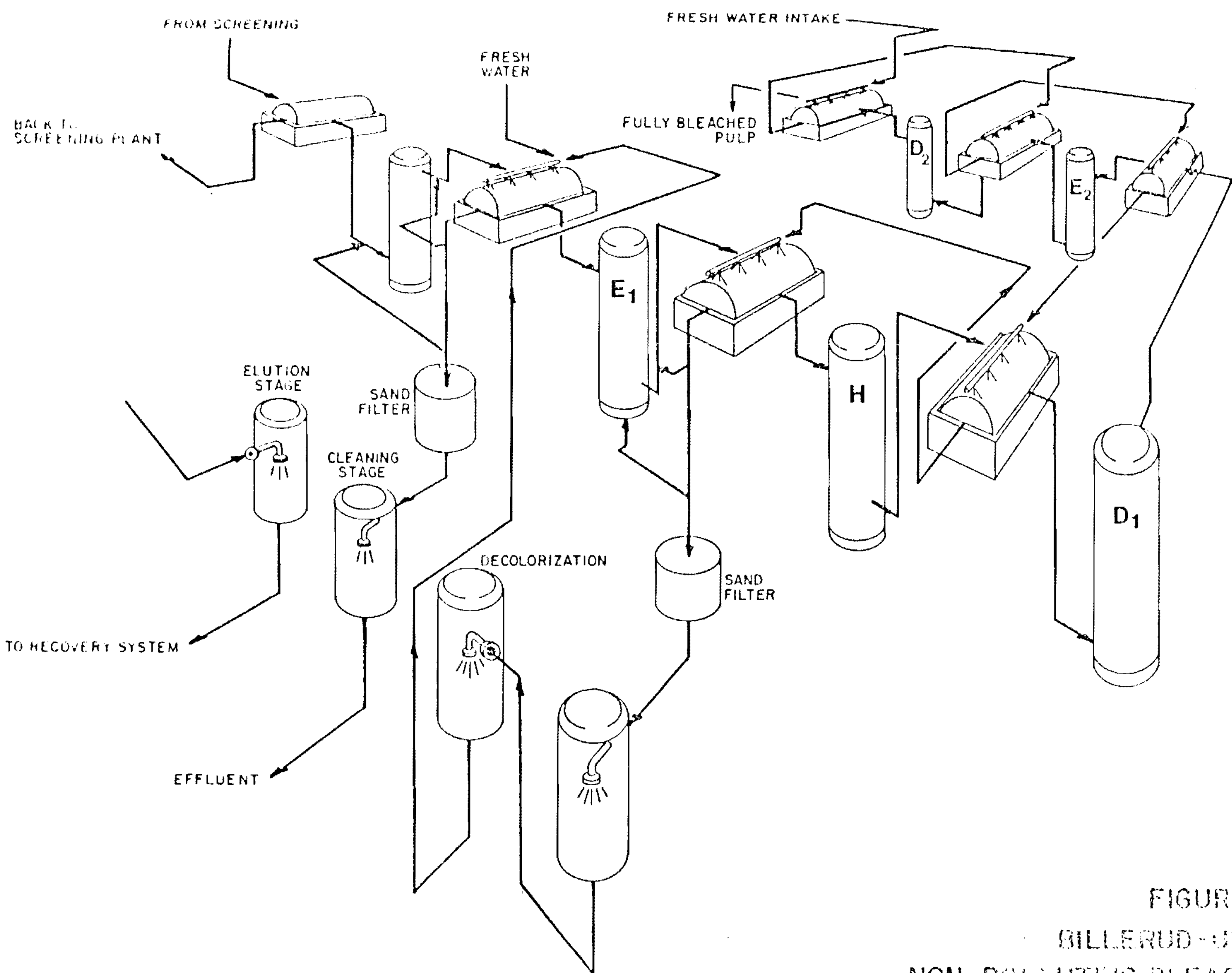


FIGURE VII-35
BILLERUD-UDDEHOLM
NON-POLLUTING BLEACH PLANT

An Assessment of the Potential for Water Reuse in the Pulp and Paper Industry

QUARTERLY PROGRESS REPORT

December 1981 - February 1982

Prepared for

The Office of Water Research & Technology
United States Department of the Interior
Under Research Grant #14-34-0001-1468
Starting Date: September 1, 1981

Prepared by

Georgia Institute of Technology
Engineering Experiment Station
Atlanta, Georgia 30332

March 1982

TABLE OF CONTENTS

	Pages
INTRODUCTION	1
REFINING THE CHARACTERISTICS OF THE PULP AND PAPER INDUSTRY	1
ASSEMBLING MAJOR CONSTRAINTS WHICH LIMIT WATER REUSE	13
REFINING THE COMPUTER TO ALLOW WATER REUSE OPTIMIZATION STUDIES	15
ANALYZING PROCESS POTENTIALS FOR WATER REUSE	20
SCOPE LIMITATIONS AND FUTURE PLANS	20
REFERENCES	23
APPENDIX A - MILLS IDENTIFIED BY LOCATION AND TYPE	24

LIST OF TABLES

	Page
Table 1 - Manufacturing Water Use by Industry, "1975"	5
Table 2 - Pulp and Paper Industry Subcategories	7
Table 3 -Production and Water Usage Statistics For Pulp and Paper Industry by Basic Subcategory	8
Table 4 - Ten Mill Subcategories Recommended For Study	10
Table 5 - Paper Manufacturing Fresh-Water Withdrawal and Consumption	12
Table 6 - Potential Problems Encountered in Water Reuse in Paper and Board Manufacture	13
Table 7 - Maximum Permissible Limits (PPM) Standard For Process Water	14
Table 8 - Typical Water (Fresh and Reuse Consumption by Major Subprocess in Unbleached Kraft Mills	21

LIST OF FIGURES

	Page
Figure 1 Fresh Water Withdrawals By Paper & Allied Products Industries	3
Figure 2 - Fresh Water Withdrawals by Major Industries	3
Figure 3 - Purpose of Fresh Water Intake by Major Industries	4
Figure 4 - Water Rources Council Regions	11
Figure 5 - Diagram of Kraft/Alkaline Pulping/Paper Process	16
Figure 6 - Diagram of Sulfite Pulping/Paper Process	17
Figure 7 - Diagram of Semichemical Pulping/Paper Process	18
Figure 8 - Diagram of Nonintegrated Fine Process	19

INTRODUCTION

This report highlights the technical progress made from December 1 through February 28 in evaluating the potential for water reuse in the pulp and paper industry. The emphasis of this quarter's work has been:

- Refining the characteristics of the pulp and paper industry
- Assembling major constraints which limit water reuse
- Refining the computer model to allow water reuse optimization studies
- Making preparations for mill visits

In addition to the above activities, the study team has identified a target group within the pulp and paper industry which represents the major users of water in this sector and therefore the primary candidates for expanded water reuse.

REFINING THE CHARACTERISTICS OF THE PULP AND PAPER INDUSTRY

The United States dominates world production and consumption of pulp, paper and paperboard products. Due to the size of the industry, the relatively low-cost of timber, and the current expansions, the U.S. can be expected to maintain its major role in world production. Georgia Tech has identified over 700 facilities in the United States involved in the manufacture of pulp, paper, and paperboard products (represented by Standard Industrial Classification (SIC) subgroups 2611, 2621 and 2631). These three subcategories of SIC 26 (Paper and Allied Products) are of primary interest to this study because together they account for 96% of this industry's total fresh water withdrawal (the volume of water taken into a manufacturing plant from an outside source). The fractional breakdown of water withdrawals for the industry is shown in Figure 1.

The Paper and Allied Products group ranks third in terms of fresh water withdrawals by manufacturing industries accounting for 17% of all industrial withdrawal. As shown in Figure 2 only Primary Metals (SIC 33) and Chemical & Allied Products (SIC 28) have greater water intakes than the paper industry.[1] By the year 2000, the paper industry is projected to be the largest manufacturing water user, both in terms of withdrawals and consumption.[2] Consumption is considered the difference between the volume of water that is withdrawn and that discharged. It is that water consumed in the production process, evaporated in cooling towers or sludge driers and consumed in the product.

The use of fresh water intake by major industries is shown in Figure 3.[1] Unlike the other major water using industries which use the majority of their water withdrawn for cooling, the paper industry uses only 34% for cooling purposes and more than 60% in the manufacturing process itself. When comparing the amount of water used for processing by the major industries, the paper industry, using 5,147 mgd, is seen to be the single largest industrial process water user.

Withdrawals are strongly influenced by those internal and external factors that encourage recycling (internal use of water by the original user prior to discharge to a treatment system or other point of disposal). There has been a long-term trend toward increased use of recycled water. The recycling of process water within pulp and paper mills is an attractive option for several reasons:

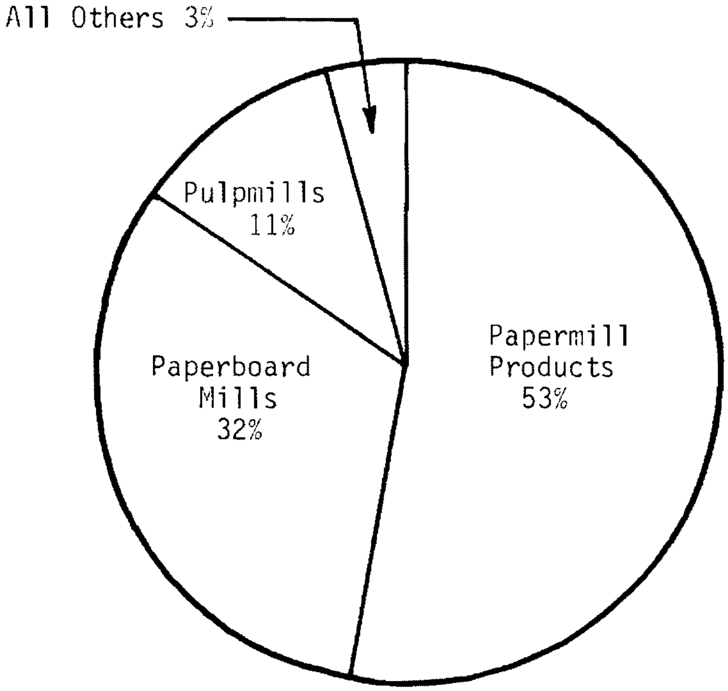


FIGURE 1

Fresh Water Withdrawals By Paper & Allied Products Industries

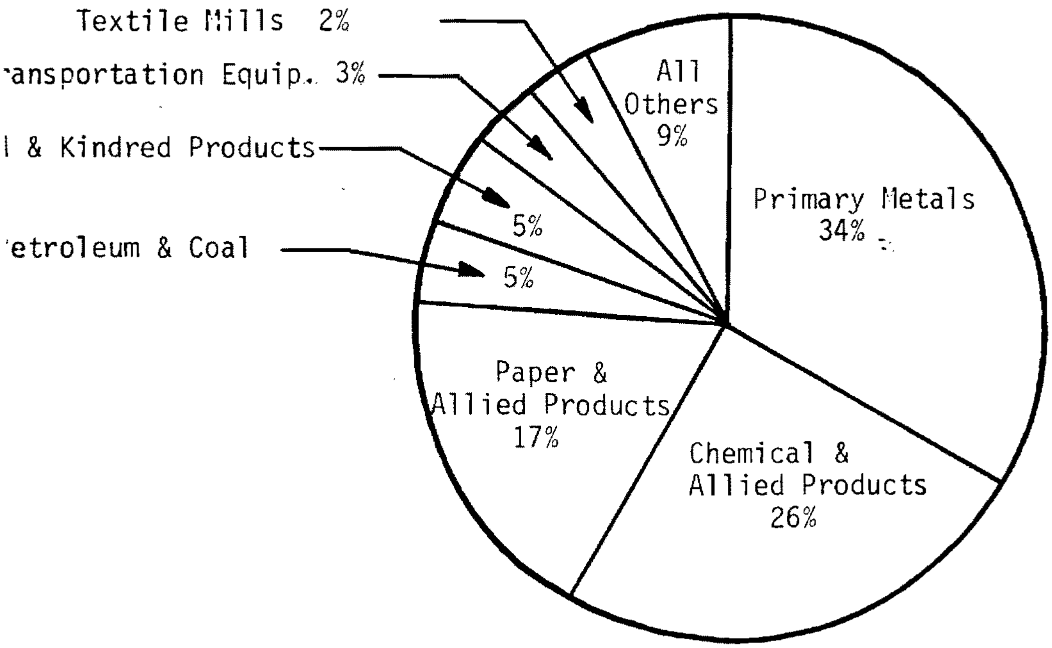


FIGURE 2

Fresh Water Withdrawals By Major Industries

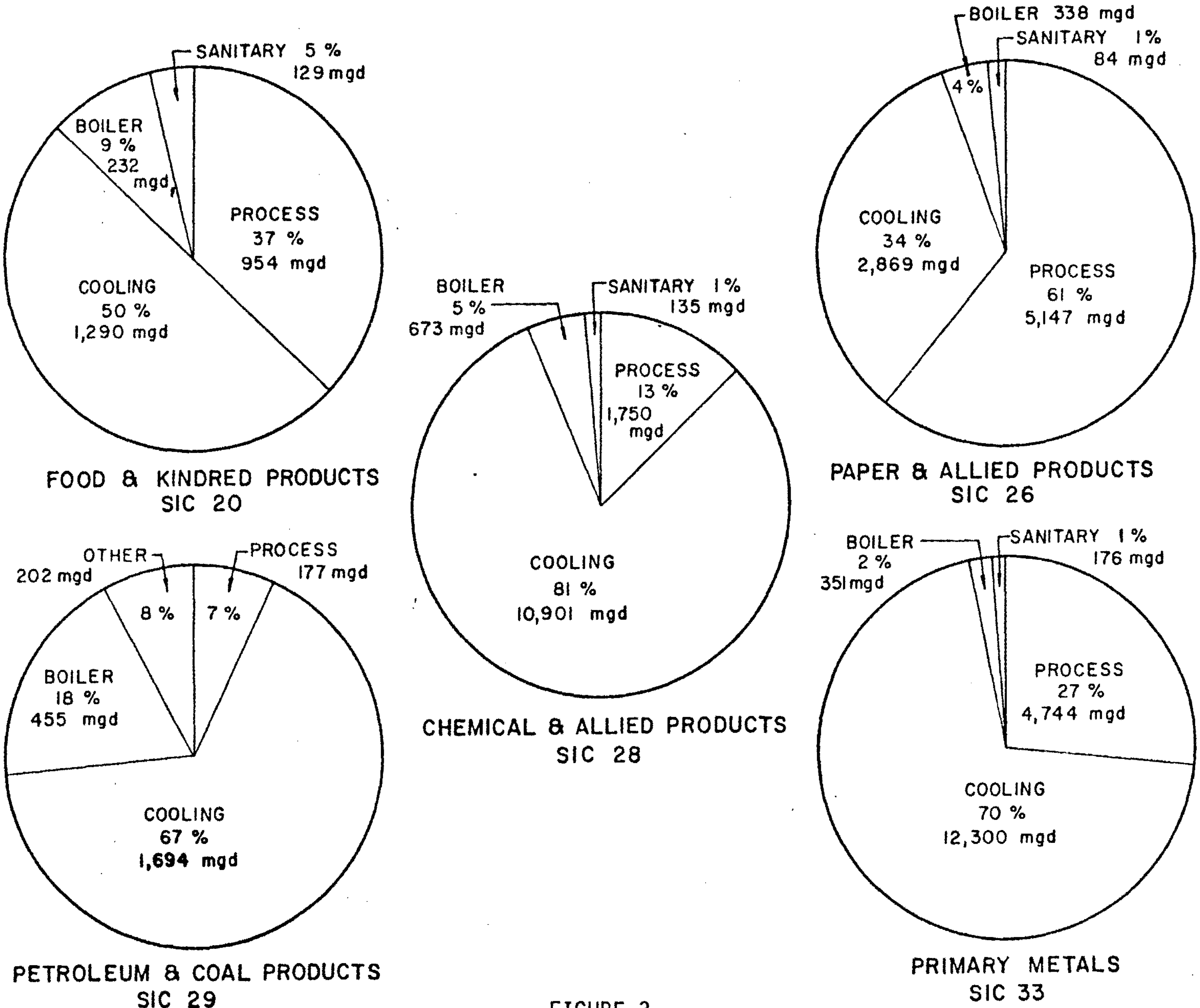


FIGURE 3

Purpose Of Fresh Water Intake By Major Industries

1. Lower fresh water use and cost
2. Greater solids recovery
3. Greater heat recovery and reduced effluent volume and cost
4. In-plant recycle is completely within the control of the mill

As shown in Table 1, paper and allied products industry has a recycle ratio of 2.9 which is the highest of all industrial groups except for the petroleum and coal products group.[2]

TABLE 1. MANUFACTURING WATER USE BY INDUSTRY, "1975"
(billion gallons per day)

Industry	Total water withdrawal[a]	Recirculation ratio	Gross water use
Chemicals and allied products	19.4	2.1	40.1
Primary metals	18.9	1.5	28.2
Paper and allied products	8.9	2.9	26.1
Petroleum and coal products	4.7	5.0	23.7
Food and kindred products	2.9	1.6	4.5
Transportation equipment	1.5	2.6	3.7
Textile mill products	0.6	2.8	1.7
All other manufacturing	4.8	1.8	8.6
National average	61.7	2.2	136.6

[a]Includes brackish and saline water.

For the purpose of evaluating water requirements, it was necessary to categorize the industry into functional subgroups that have similar production processes influencing water useage. In order to develop wastewater effluent limitations for the industry the U.S. Environmental Protection Agency subcategorized the industry based on current information on factors such as: size and age of plant, raw material, processes employed, final products, water use and waste constituents.[3] This subcategorization scheme, as shown in Table 2, was adopted by the study team. A thorough statistical summary of these categories was complied to allow for direct comparison based on: number of mills, product capacity, and water requirements. This data is shown in Table 3. By evaluating this data, it was found that less than 170 mills residing in ten categories provide nearly 72% of all production and account for 85% of the total water withdrawn. Based on these findings it was proposed that the study team focus on these ten categories alone to provide a more accurate assessment of the potential for water reuse by the pulp and paper industry. These ten categories are shown in Table 4. The plants falling in each of these categories are listed by State in Appendix A.

TABLE 2. PULP AND PAPER INDUSTRY SUBCATEGORIZATIONS

Integrated	Secondary Fibers
Dissolving Kraft	Deink
Market Bleached Kraft	o Fine Papers
BCT Bleached Kraft	o Tissue Papers
Fine Bleached Kraft	o Newsprint
Soda	Tissue from Wastepaper
Unbleached Kraft	Paperboard from Wastepaper
o Linerboard	Wastepaper-Molded Products
o Bag and Other Mixed Products	Builders' Paper and Roofing Felt
Semi-Chemical	
Unbleached Kraft and Semi-Chemical	
Dissolving Sulfite Pulp	**Nonintegrated**
o Nitration	Nonintegrated-Fine Papers
o Viscose	Nonintegrated-Tissue Papers
o Cellophane	Nonintegrated-Lightweight Papers
Papergrade Sulfite (Blow Pit Wash)	
Papergrade Sulfite (Blow Pit Wash)	Nonintegrated-Filter and Nonwoven Papers
Papergrade Sulfite (Drum Wash)	
Groundwood - Coarse, Molded, and News (C, M, N) Papers	
Groundwood - Fine Papers	
Groundwood-Chemi-Mechanical	

TABLE 3. PRODUCTION AND WATER USAGE STATISTICS FOR PULP AND PAPER INDUSTRY BY BASIC SUBCATEGORY

Mill Category	# of Mills	(e) Avg t/d	(f) Total t/d	Rank by prod.	(g) Avg Kgal/t	Rank by Kgal/t	(h) Kgal/d	Rank Kgal/d
Dissolving Kraft	3	60	180	27	47.5	3	8,550	26
Market Bleached Kraft	10	540	5,400	11	38.3	6	206,820	7
Bct Bleached Kraft [a]	8	871	6,968	9	36.0	7	250,848	5
Alkaline-Fine w/o GWD	16	630	10,080	6	27.5	10	277,200	2
w/ GWD	4	919	3,676	14	30.9	8	113,588	11
Unbleached Kraft Linerboard	17	958	16,286	3	11.4	24	185,660	9
Unbleached Kraft Bag and Other	12	888	10,656	5	24.8	13	264,269	3
Semi-Chemical	19	400	7,600	8	7.4	27	56,240	15
Unbleached Kraft & Semi-Chemical	10	1531	15,310	4	12.8	23	195,968	8
Dissolving Sulfite Pulp	6	543	3,258	18	64.8	1	211,118	6
Papergrade Sulfite	17	374	6,358	10	41.0	4	260,678	4
Groundwood - Thermo-Mechanical	3	326	978	21	13.8	22	13,496	23
Groundwood - CMN Papers	6	323	1,938	19	26.1	11	50,582	17
Groundwood - Fine Papers	8	449	3,592	15	16.4	20*	58,909	14

Mill Category	# of Mills	(e) Avg t/d	(f) Total t/d	Rank by prod.	(g) Avg Kgal/t	Rank by Kgat/t	(h) Kgal/d	Rank Kgal/d
Integrated Miscell- aneous Mills[c]	88	700	61,600	1	24.2	14	1,490,720	1
Deinking Fine Paper	5	230	1,150	20	21.1	16	24,265	21
Newsprint[d]	3	N/G	N/A	N/A	16.2	21	N/A	N/A
Tissue from Wastepaper								
Industrial Tissue	9	17	153	28	19.3	18	2,953	28
Sanitary Tissue	12	24	288	26	22.5	15	6,480	27
Paper from Wastepaper	146	138	20,148	2	4.2	28	84,621	12
Wastepaper - Molded Products	15	44	660	24	16.4	20*	10,824	24
Builders' Paper and Roofing Felt	57	88	5,016	12	2.0	29	10,032	25
Secondary Fibers Miscellaneous	17	227	3,859	13	9.5	26	36,660	18
Nonintegrated - Fine Papers	41	226	9,226	7	18.4	19	170,494	10
Nonintegrated - Tissue Papers	26	127	3,302	16	20.4	17	67,361	13
Nonintegrated - Lightweight Papers	17	53	901	23	56.8	2	51,177	16
Nonintergrated - Filter & Non-woven Papers	14	4	56	29	39.8	5	2,229	29
Nonintegrated - Paperboard	12	48	576	25	25.6	12	14,746	22
Nonintegrated - Miscellaneous	34	97	3,298	17	11.0	25	36,278	19
		Total	202,553				4,162,766	

(a) paperboard builders' paper
(b) coarse, molded, newsprint
(c) multiple pulping operations or miscellaneous pulping not in other integrated categor
(d) production data confidential
(e) average for mills reporting
(f) t/d based on average for mills reporting x # of mills in category
(g) average for mills data
(h) average for mills report x calculated tons per day
* tied

TABLE 4. TEN MILL SUBCATEGORIES RECOMMENDED FOR STUDY

Market Bleached Kraft
Board, coarse, and Tissue) Bleached Kraft
Alkaline Fine w/o Groundwood
Unbleached Kraft Linerboard
Unbleached Kraft & Semi-Chemical
Dissolving Sulfite Pulp
Papergrade Sulfite
Integrated Miscellaneous Mills
Nonintegrated Fine Papers
Unbleached Kraft Bag and Other

For compiling and analyzing water resources data, the Nation has been divided into 21 major water regions and further subdivided into 106 subregions by the U.S. Water Resources Council. The 21 water resources regions shown in Figure 4, are hydrologic areas that have either the drainage area of a major river or combined drainage areas of a series of rivers. A wealth of data on water supply, water needs and availability, and wastewater discharges has been published in "The Nations Water Resources, The Second National Assessment."[2] This report identifies problems such as: inadequate surface-water supply, overdraft of groundwater, pollution of surface water and pollution of groundwater for the regions. All three factors are important in the context of this study. Therefore, these water resource regions are being used as a means of grouping pulp and paper mills.

The fresh water withdrawals and consumption for the pulp and paper industry are tabulated by water resource region in Table 5.[2] The regions of greatest water use are the South Atlantic-Gulf, Pacific Northwest, New England, Mid-Atlantic, Great Lakes and Lower Mississippi. These six region collectively account for 68% of the daily water withdrawed by the paper manufacturing sector.

FIGURE 4

Water Resources Council Regions

TABLE 5. PAPER MANUFACTURING FRESH-WATER WITHDRAWALS AND CONSUMPTION "1975," 1985, 2000

(million gallons per day)

Region	Withdrawal			Consumption		
	"1975"	1985	2000	"1975"	1985	2000
New England (1)	962	520	395	86	158	313
Mid-Atlantic (2)	745	460	389	76	146	305
South Atlantic-Gulf (3)	2,111	1,974	1,875	262	614	1,492
Great Lakes (4)	982	534	427	143	213	334
Ohio (5)	224	151	133	23	46	101
Tennessee (6)	381	268	246	41	85	196
Upper Mississippi (7)	348	140	104	20	38	80
Lower Mississippi (8)	517	403	381	46	119	304
Souris-Red-Rainy (9)	86	33	22	9	13	17
Missouri (10)	2	3	5	0	1	4
Arkansas-White-Red (11)	200	125	110	30	50	86
Texas-Gulf (12)	245	200	218	38	79	174
Rio Grande (13)	0	0	0	0	0	0
Upper Colorado (14)	0	0	0	0	0	0
Lower Colorado (15)	15	18	26	3	8	22
Great Basin (16)	0	0	0	0	0	0
Pacific Northwest (17)	1,326	868	739	197	312	588
California (18)	170	212	228	60	101	178
Total, Regions 1-18	8,314	5,909	5,298	1,034	1,983	4,194
Alaska (19)	124	86	78	24	37	62
Hawaii (20)	0	0	0	0	0	0
Caribbean (21)	0	0	0	0	0	0
Total, Regions 1-21	8,438	5,995	5,376	1,058	2,020	4,256

ASSEMBLING MAJOR CONSTRAINTS WHICH LIMIT WATER REUSE

A major concern in reusing water is maintaining suitable quality to prevent production problems. Our research has uncovered a number of production problems which have resulted from increased water reuse. These problems can be grouped into three categories: the buildup of dissolved solids, the buildup of suspended solids, and the buildup of thermal energy. Table 6 below presents the fasion in which these problems present themselves.

TABLE 6. POTENTIAL PROBLEMS ENCOUNTERED IN WATER REUSE IN PAPER AND BOARD MANUFACTURE

Dissolved Solids Buildup	Suspended Solids Buildup	Thermal Energy Buildup
Slime	Dirt	Temperature
Foam	Erosion	Sizing Problems
Pitch	Fines	Machine Room Temperature
Corrosion	Felt Plugging	Reduced Vacuum Pump Capacity
Sizing	Wire Plugging	
Color	Wire Life	
Product Mottle	Felt Life	
pH Control	Reduced Drainage Rate	
Precipitation	Shower Plugging	
Scale		
Odor		

Source: National Council for Air and Stream Improvement: Special Report 287, c. 8/76.

In order to prevent such problems, constraints have been set on overall process water quality. Listed below in Table 7 are water quality standard set by The Technical Association of the Pulp and Paper ndustry (TAPPI).

TABLE 7. MAXIMUM PERMISSIBLE LIMITS (PPM) STANDARD FOR PROCESS WATER

Substance	Fine Papers	Groundwood Papers	Kraft Paper Bleached	Kraft Paper Unbleached
Turbidity as SiO_2	10	50	40	100
Color in platinum units	5	30	25	100
Total hardness as $CaCO_3$	100	200	100	200
Calcium hardness as $CaCo_3$	50	-	-	-
Alkalinity to methyl orange $CaCO_3$	75	150	75	150
Iron as Fe	0.1	0.3	0.2	
Manganese as Mn	0.05	0.1	0.1	
Residual chlorine as Cl_2	2.0	-	-	-
Silica (soluble) as SiO_2	20	50	50	100
Total dissolved solids	200	500	300	500
Free carbon dioxide as CO_2	10	10	10	10
Chlorides as chlorine	-	75	-	-

Source: Tappi Standards

The study team is currently applying these standards in the operation of its computer model. Further refinements of these constraints may be necessary to more accurately reflect the variations in grade of pulp and paper production being studied as the study progresses. For instance certain grades of pulp and paper such as food papers, filter papers and dissolving pulps, may require constraints more stringent than those listed above while more common pulp and paper grades require less restrictive constraints.[4]

REFINING THE COMPUTER TO ALLOW WATER REUSE OPTIMIZATION STUDIES

During the past quarter, the use of GEMS computer model as progressed from the point of general familiarization to actual mill modeling. The model currently on the Georgia Tech computer system contains programs for the cooking, washing and screening processes of kraft pulping and the general pulp drying operation of paper production. Entry of programs to represent the chemical recovery process and the bleaching operation are expected to be completed no later than the end of March. All of the above programs are being extracted from material supplied with the GEMS model.

The model as it currently exists (without chemical recovery or bleaching) models those subprocesses of pulp and paper production displayed in Figures 5 through 8. While the thrust of the current program is toward kraft operations, modifications to accommodate alkaline, sulfite and other production categories will be made by modifying the digestion, bleaching and chemical recovery programs. These modifications are expected to be minor from the standpoint of computer programming and should present no special problems.

When complete, the model will provide outputs which can be compared to actual mill data. This will allow the study team to determine the validity of the calculation process, the reuse assumptions and the water quality constraints imposed. Mill data gained from visits will be used to answer specific questions about subprocess restrictions and actual practices so that the final model reflects true conditions.

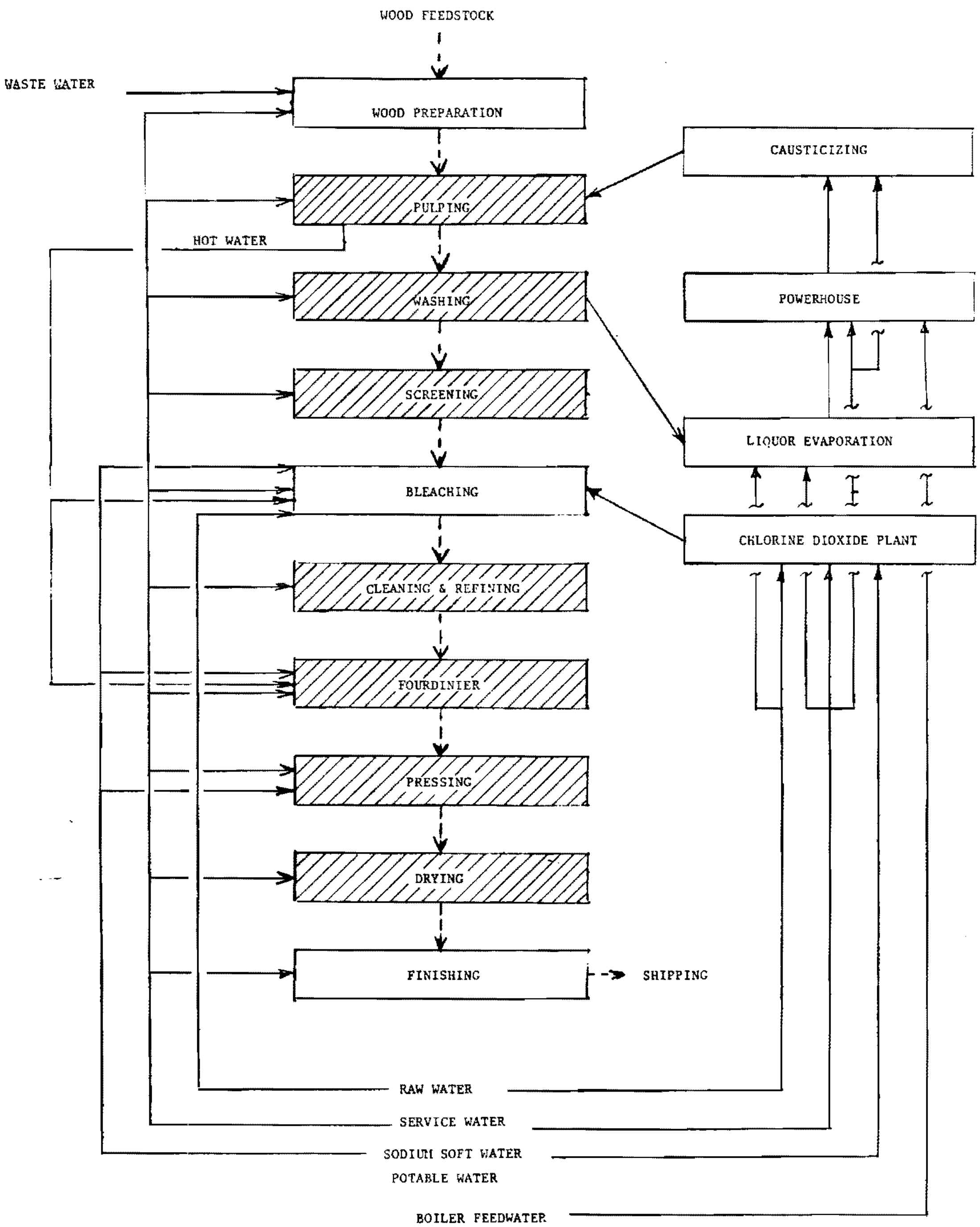


FIGURE 5

Diagram Of Kraft/Alkaline Pulping/Paper Process

Note: Shaded area currently represented on computer model

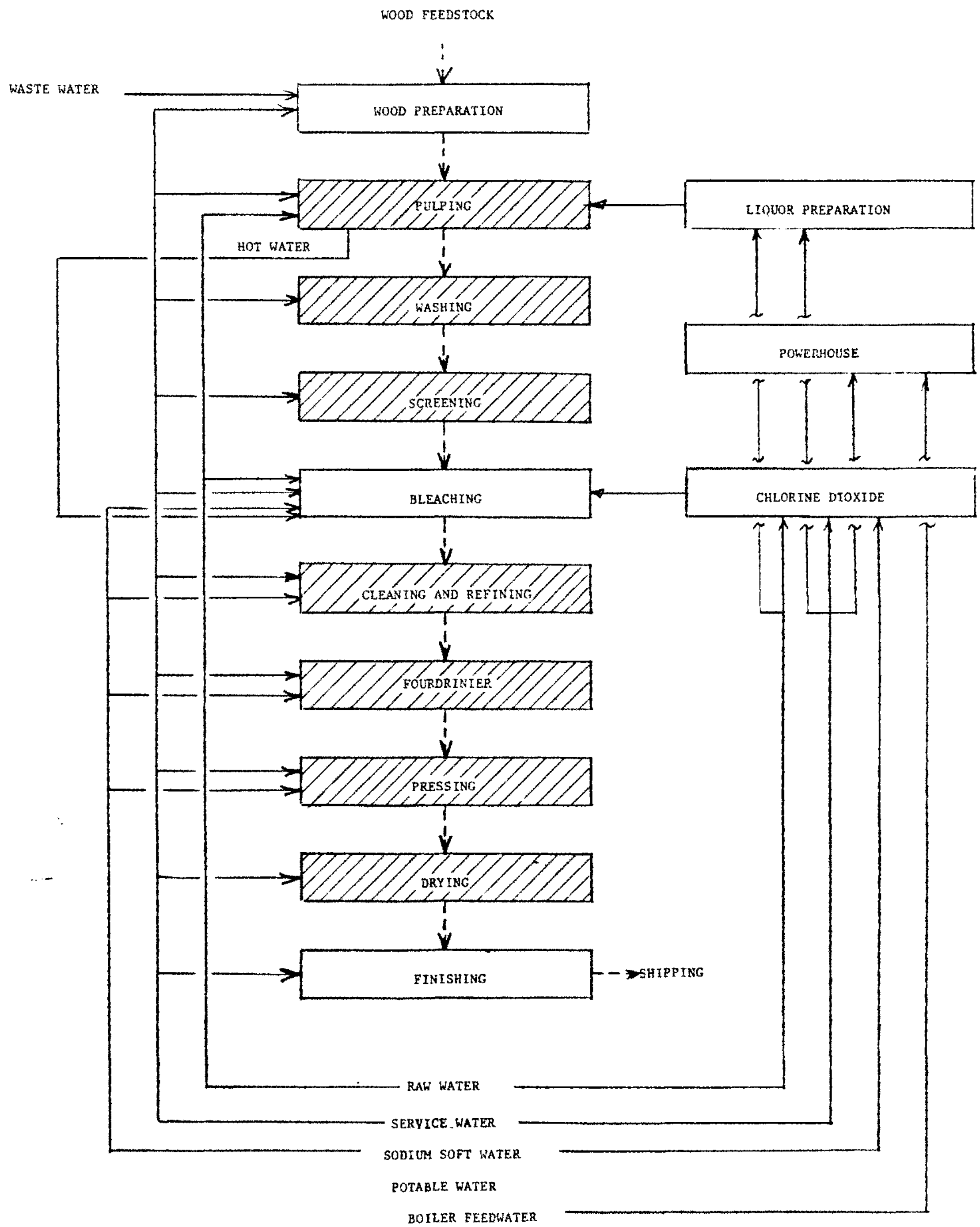


FIGURE 6

Diagram Of Sulfite Pulping/Paper Process

Note: Shaded area currently represented on computer model

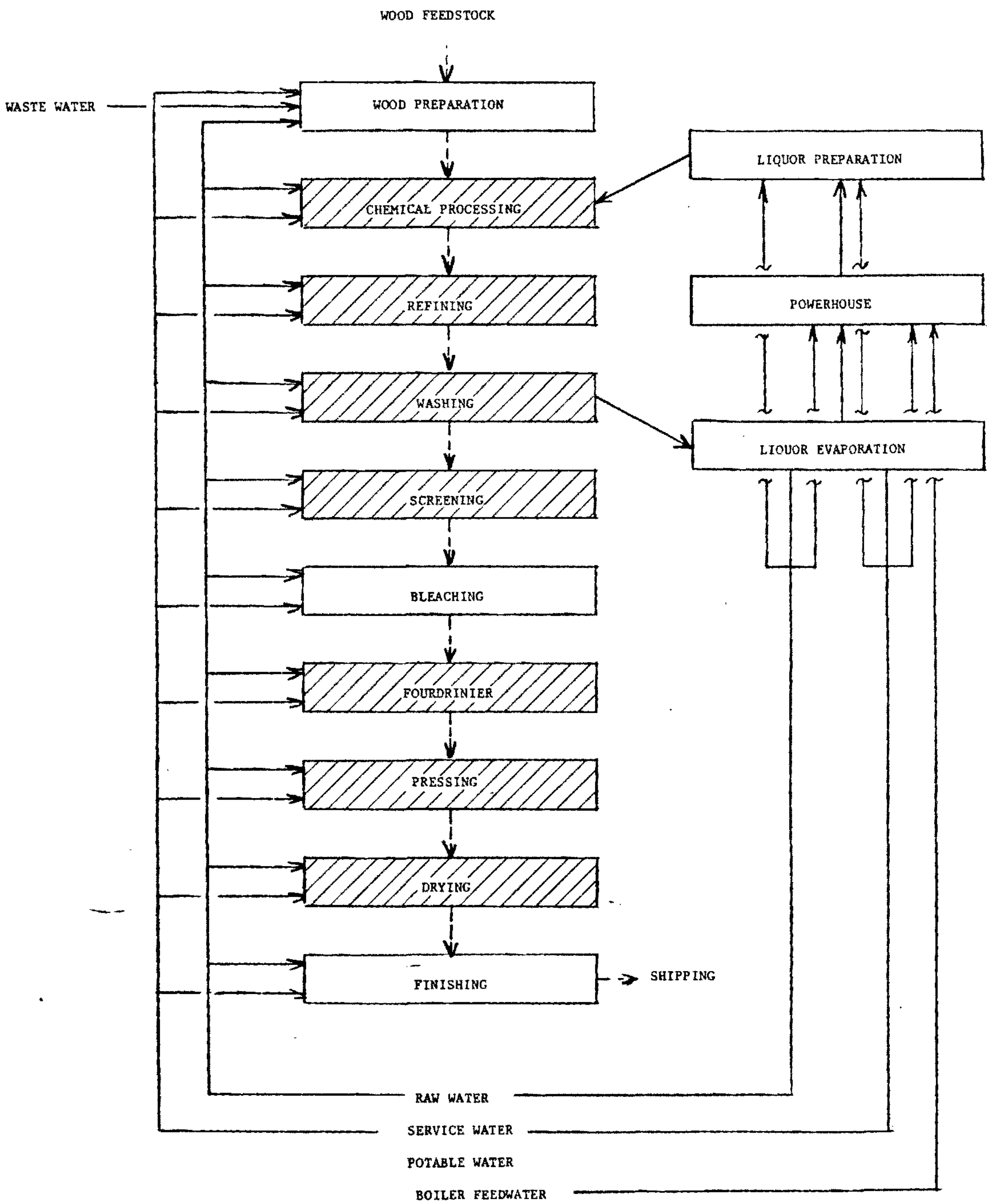


FIGURE 7

Diagram Of Semichemical Pulping/Paper Process

Note: Shaded areas represented on computer model

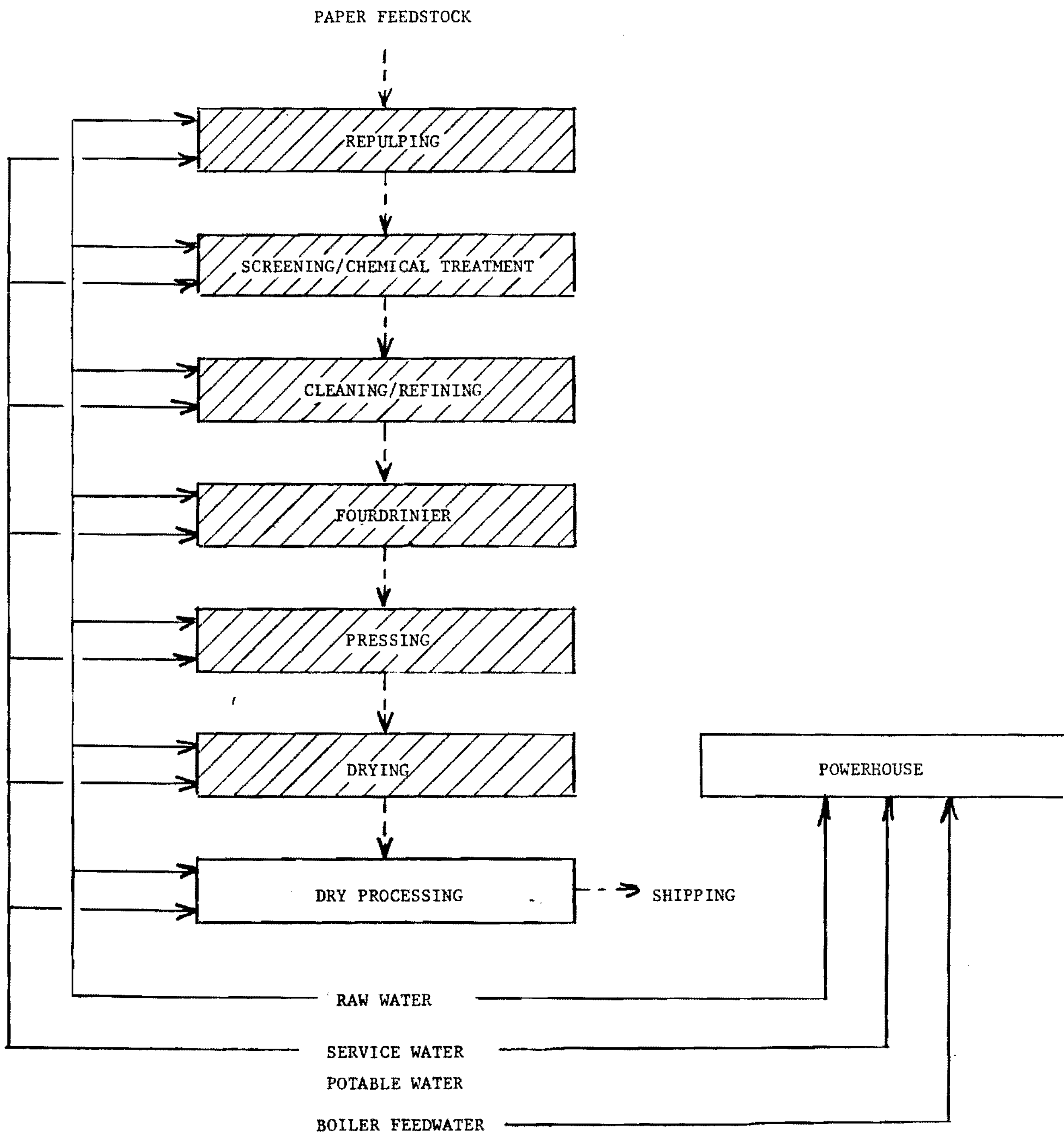


FIGURE 8

Diagram Of Nonintegrated Fine Process

Note: Shaded area currently represented on computer model

ANALYZING PROCESS POTENTIALS FOR WATER REUSE

Based on a preliminary assessment of pulp and paper mill subprocesses, it has been concluded that the potential for water reuse is strongest in the areas of stock dilution, showering, sealing (as in vacuum pumps), cooling-heating, and cleanup. Table 8 shows a breakdown of water usage in these areas for a general unbleached kraft mill. This data is believed to be typical for all mill types in that the most significant usage water is for stock dilution on the paper machine.

In evaluating strategies for water reuse, the study team is will examine water quality and quantity constraints in various subprocess areas (such as the above-mentioned areas), to determine if current fresh water usage can be reduced or replaced by either untreated or semi-treated waste water.

SCOPE LIMITATION AND FUTURE PLANS

On February 24, a request was forwarded to limit the number of mill categories studied. Based on our research findingss, it was revealed that while there are over 700 pulp and paper mills in the United States composed into 29 different categories, less than 170 mills residing in ten categories provide nearly 72 percent of all pulp and paper production and withdraw over 85 percent of the total annual water used in this sector.

TABLE 8. TYPICAL WATER (FRESH AND REUSE CONSUMPTION BY MAJOR SUBPROCESS IN UNBLEACHED KRAFT MILLS

Dilution Water Use	
(Excludes headbox loop recirculation from 3% machine stock to 0.5% headbox stock to 3% (wire solids)	
Stock dilution (12% off the washer or decker or high density storage to 3% machine stock)	6000 gpt
Excess dilution water from high density storage stock (12% solids to the paper web entering the dryer at 38% solids)	1370 gpt
Cleaner dilution	290-320 gpt
Pulper makedown (92% solids to 3% solids) Potentially intermittent use	3200-3560 gpt
Showering Water Use	
Miscellaneous paper machine showers 1. Wire knockoff Estimated 2. Wire cleaning at 60% 3. Wire return roll of flow 4. Headbox showers 5. Breast roll 6. Trim knockoff and cleaning 7. Internal & external couch roll showers 8. Internal press roll showers 9. Felt lub 10. Deckles and trim squirt	3200-3560 gpt
Press felt washing	2140-2370 gpt
Grooved roll shower	290-320 gpt
Sealing Water Use	
Gland seal water 860-950 gpt	
Vacuum pump seal	1300-1440 gpt
Cooling Water Use	
Cooling water 1. Heat exchangers 2. Sweat dryer system 3. Mechanical cooling units 4. Air compressors 5. Hydraulic system 6. Brake drums 7. Miscellaneous equipment	3400-3780 gpt
Miscellaneous Uses	
Equipment clean-up, etc.	1070-1190 gpt

Source: National Council of Air and Stream Improvement: Special Report 339, C.1980.

Assuming this limitation in scope is accepted, the study team will select mills to visit from the list in Appendix A.

Work to be conducted in the third quarter will include the following priority items:

1) Completion of program entry and modifications to the computer model. This will allow the study team to actively begin simulating key production subprocesses utilized in the ten mill categories studied.

2) Initiation of mill visits to selected sites to collect detailed reuse data..

In addition to these items the study team will also begin assimulating data collected from the literature and from mill visits, to try and identify not only the extent of current water reusemill in each category but also the extent to which water is recycled in each major subprocess. To the extent possible, water quality constraints will also be refined to address major subprocess restrictions in each of the ten mill categories selected.

REFERENCES

1. Department of the Interior, Office of Water Research and Technology, "Water Reuse and Recycling", April 1979.

2. U.S. Water Resources Council, "The Nation's Water Resources, The Second National Assessment", December 1978.

3. U.S. Enviromental Protection Agency, "Development Document for Proposed Effluent Limitations Guidelines and Standards for the Pulp, Paper and the Builders' Paper and Board Mills", December 1980.

4. Casey, James, "Pulp and Paper Chemistry and Chemical Technology, Vol. II", Wiley - Interscience Publishers, 1980.

APPENDIX A

PULP AND PAPER MILLS BY CATEGORY

This appendix presents a listing of mills which fall into each of the ten categories recommended for further study. Listed below in Table A-1 are the category breakdowns and the codes assigned each. These codes are presented after each mill name and address in the listing that follows. For simplicity two of the original ten categories presented in our February 24 letter have been merged. These categories are unbleached Kraft linerborad and unbleached kraft bag and other. The new single designation is unbleached kraft linerboard and bag.

TABLE A-1. IDENTIFICATION CODES FOR MILL CATEGORIES

Integrated Segment	Code
Market Bleached Kraft	Ib
Board, coarse, and Tissue) Bleached Kraft	Ic
Alkaline Fine w/o Groundwood	Id
Unbleached Kraft Linerboard & Bag	Ie
Unbleached Kraft & Semi-Chemical	If
Dissolving Sulfite Pulp	Ig
Papergrade Sulfite	Ih
Integrated Miscellaneous Mills	Ii
Nonintegrated Segment	
Nonintegrated Fine Papers	IIa

PULP & PAPER MILLS

ALABAMA

Company	Location	Mill Type*	Production (TPD)**
Alabama River Pulp Co.	Claiborn, AL	Ib	1100
Allied Paper Inc.,	Jackson, AL	Ik (Ie,Ib, Ic)	600
American Can Co.	Butler, AL	Ik (Ib,Ic)	900
Champion International Corp.	Courtland, AL	Ik(Ib,Ic)	700
Container Corp. of America	Brewton, AL	IK(Ib, Ic, Ie)	1150
Georgia Kraft Co.	Mahrt, AL	Ie	975
Gulf States Paper Corp.	Demopolis, AL	Ik(Ib,I c,)	500, 25
Hammermill Papers Group,	Selma, AL	Ik(Ib,I c)	530
International Paper Co.	Mobile, AL	Ik(Ib, Ic, Ie, Ij)	1225, 250
Kemberly-Clark Corp.	Coosa Pines, AL	Ib, c, Ij	1700
MacMillan Bloedel Inc.	Pine Will, AL	Ie	1100
Union Camp Corp.	Montgomery, AL	I	2050

See Table A-1*

TPD - Tons Per Day**

ALASKA

Company	Location	Mill Type	Production (TPD)
Alaska Lumber & Pulp Co. Inc.	Sitka, AK	Ia	600
Louisiana-Pacific Corp.	Ketchikan, AK	Ik(Ia, Ih, (Ii)	600

ARIZONA

Company	Location	Mill Type	Production (TPD)
Southwest Forest Industries,	Snow Flake, AZ	Ik(Ib,Ic,Ic,Ij),	90, 550 215

ARKANSAS

Company	Location	Mill Type	Production (TPD)
Arkansas Kraft Corp.	Morrilton, AR	Ik(Ie)	800, 300
Georgia-Pacific Corp.	Crosset, AR	Ik(Ib,Ic, Ie)	1150, 1450
International Paper Co.	Camden, AR	Ie	750
International Paper Co.	Pine Bluff, AR	Ik(Ib,Ic,Ie, Ij)	1100, 500
Nekossa Papers Inc.	Ashdown, AR	Ik(Ib, Ic)	1300
Potlatch Corp.	McGehee, AR	Ik(Ib, Ic)	450
Weyerhaueser Co.	Pine Bluff, AR	Ie	300

CALIFORNIA

Company	Location	Mill Type	Production (TPD)
Crown Simpson Pulp Co.	Fairheaven, CA	Ib, c	600
Louisiana-Pacific Corp.	Antioch, Ca	Ie, If	600, 175
Simpson Paper Co.,	Anderson, CA	Ib, c	175
Simpson Paper Co.	Pomona, CA	Ik(Ib, Ic Ie, Ih)	280, 50
Simpson Paper Co.	Ripon, CA	IIa	85

CONNECTICUT

Company	Location	Mill Type	Production (TPD)
Connecticut Paperboard Cor.	Uncasville	IIa	200

FLORIDA

Company	Location	Mill Type	Production (TPD)
Alton Packaging Corp.	Jacksonville, FL	Ie	650
The Buckeye Cellulose Corp.	Perry, FL	Ik(Ia, Ib, Ic)	1000
Container Corp. of America	Fernandina Bch, FL	Ik(Ic, If)	1400, 350
Georgia Pacific Corp	Palatka, FL	Ik(Ib,Ic, Ie)	400, 750
ITT Rayonier, Inc.	Fernandina Bch, FL	Ik(Ih, i)	450
St. Joe Paper Co.	Port St. Joe, FL	Ik(Ib, Ic)	450, 850
St. Regis Paper Co.	Jacksonville, FL	Ie	1400
St. Regis Paper Co.	Pensacola, FL	Ik(Ib, Ic, Ie)	275, 645
Southwest Forest Industries	Panama City, FL	IkIb, Ic, Ie)	1450

GEORGIA

Company	Location	Mill Type	Production (TPD)
Brunswick Pulp & Paper Co.	Brunswick, GA	Ik(Ib, Ic)	1700
Continental Forest Industries	Portwentworth, GA	Ie	700
Georgia Kraft Co.	Krannert, GA	Ie	1600
Georgia Kraft Co.	Macon, GA	Ie	900
Gilman Paper Co.	St. Marys, GA	Ik(Ib, Ic, Ie)	1200
Great Southern Paper Co.	Cedar Springs, GA	Ik(Ie, If)	1860, 400
ITT Rayonier Inc.	Jesup, GA	Ik(Ib, Ic)	1250
Interstate Paper Corp.	Riceboro, GA	Ic	550
Owens-Illinois Inc.	Valdosta, GA	Ie	900
Union Camp Corp.	Savannah, GA	Ie	2550, 300

IDAHO

Company	Location	Mill Type	Production (TPD)
Potlatch Corp.	Lewiston, ID	Ik(Ib,(c)	1100

ILLINOIS

Company	Location	Mill Type	Production (TPD)
Georgia-Pacific Corp	Taylorville, IL	IIa	1100

KENTUCKY

Company	Location	Mill Type	Production (TPD)
Westvaco Corp	Wickliffe, KY	Ik(Ib, Ic)	660
Williamette Industries Inc. (Western Kraft Paper Group)	Hawesville, KY	Ik(Ib, Ic, If)	300, 100

LOUISIANA

Cpmpany	Location	Mill Type	Production (TPD)
Boise Southern Co.	DeRidden, LA	Ik(Ic, Ib, Ie)	160, 1100
Continental Forest Inds.	Hodge, LA	Ik(Ie, If)	1400, 250
Crown Zellerbach Corp	Bogalusa, LA	Ik(Ib, Ic, Ie, If)	1300,330
Crown Zellerbach Corp.	St. Francisville, LA	Ie	5500
Georgia-Pacific Corp.	Port Hudson, lA	Ik(Ib, Ic)	1285
International Paper Co.	Bastrop, LA	Ik(Ib, Ic)	1000, 490
Valentine Pulp & Paper Co.	Lockport, LA	Id	115
Willemette Industries	Campti, LA	Ik(Ie)	850,100
Pineville Kraft	Pineville, LA	Ie	985

MAINE

Company	Location	Mill Type	Production (TPD)
Boise Cascade Corp.	Rumford, ME	Ik(Ic, Ib, Ie)	610, 120
Diamond International Corp.	Old Town, ME	Ik(Ib, Ic)	600
Eastern Fine Paper,Inc.	Brewer, ME	IIa	200
Fraser Paper Ltd.	Madawaska, ME	IIa	500, 670
Georgia-Pacific Corp.	Woodland, ME	Ik(Ib,Ic Ie, Ij)	900
Great Northern Paper Co.,	Millinocket, ME	Ik(Ih, Ii, Ij)	660, 700, 120
International Paper Co.	Jay, ME	Ik(Ib, Ic, Ie, Ij)	1125, 130
Lincoln Pulp & Paper Mills, Inc.	Lincoln, ME	Ik(Ib, Ic)	350
Warren Co. S.D.	Westbrook, ME	Ik(Ib, Ic)	300

MARYLAND

Company	Location	Mill Type	Production (TPD)
Westvaco Corp.	Luke, MD	Ib	770

MASSACHUSETTS

Company	Location	Mill Type	Production (TPD)
Byron Weston Co.(Div.of Crane)	Dalton, MA	IIa	45
Fitchburg Paper Co.	Fitchburg, MA	IIa	225
James River-Fitchburg, Inc.	Fitchburg, MA	IIa	60
James River-Rochester, Inc.	Adams, MA	IIa	35
Kimberly-Clark Cor.	Lee, MA	IIa	90
Linweave Inc.	Holyoke, MA	IIa	65
Nu-Valley Paper Co.	Holyoke, MA	IIa	50

MICHIGAN

Company	Location	Mill Type	Production (TPD)
Champion International Corp.	Ontonagon, MI	If	500
Georgia-Pacific Corp.	Kalamazoo, MI	IIa	470
James River-Rochester, Inc.	Rochester, MI	IIa	15
The Mead Corp.	Escanaba, MI	Ik(Ib, Ic, Ij)	700,120
Menasha Corp.	Otsego, MI	If	300
Packaging Corp. of America	Filer City, MI	If	620
Port Huron Paper Co.	Detroit, MI	Ik(Ib, Ic)	160
Simpson Paper Co.	Vicksburg, MI	IIa	100, 100
Warren CO., S.D.,	Muskegon, MI	Ik(Ib,Ic)	400

MINNESOTA

Company	Location	Mill Type	Production (TPD)
Boise Cascade Corp.	International Falls,MN	Ik(Ie, Ij, Ib,Ic)	360, 5
Potlatch Corp.	Cloquet, MN	Ik(Ib,Ic Ih,Ii,Ie)	400, 180

MISSISSIPPI

Company	Location	Mill Type	Production (TPD)
Dunn Paper Co.	Wiggins, MS	Ie	45
International Peper Co.	Moss Point, MS	Ik(Ib,Ic)	660
International Paper Co.	Natchez, MS	Ik(Ia, Ib,Ic)	1100
International Paper Co.	Vicksburg, MS	Ie	1200
St. Regis Paper Co.	Monticello, MS	Ik(Ib,Ic, Ie)	1955

MONTANA

Company	Location	Mill Type	Production (TPD)
Champion International Corp.	Missoula, MT	Ik(Ib,Ic, Ie)	135, 715

NEW HAMPSHIRE

Company	Location	Mill Type	Production (TPD)
Franconia Paper Co.	Lincoln, NH	IIa	120
Monadnock Paper Mills, Inc.	Bennington, NH	IIa	75

NEW YORK

Company	Location	Mill Type	Production TPD)
Finch, Pruyn & Co. Inc.	Glena Falls, NY	Ik(Ij,Ii)	380
Mohawk Paper Mills, Inc.	Waterford, NY	IIa	70
International Paper Co.	Ticonderuga, NY	Ik(Ib,Ic)	530
Newton Falls Paper Mill,Inc.	Newton Falls, NY	IIa	140
Simplicity Pattern Co.	Norfolk, NY	IIa	50
Georgia-Pacific Corp.	Lyon Falls, NY	IIa	120

NORTH CAROLINA

Company	Location	Mill Type	Production (TPD)
Champion International Corp.	Canton, NC	Ik(Ib,Ic)	1400
Champion International Corp.	Roanoke Rapids, NC	Ie	1100
Fedral Paper Board Co.	Riegelwood,NC	Ik(Ib,Ic)	685
Weyerhauser Co.	New Bern, NC	Ik(Ib,Ic)	725
Weyerhauser Co.	Plymouth, NC	Ik(Ib,Ic,Ie,If)	955, 450

OHIO

Company	Location	Mill Type	Production (TPD)
Glatfelter Co., PH	West Carrollton, OH	Ik(Ii)	275
The Mead Corp.	Chillclothe, OH	Ik(Ib,Ic)	600, 424
Beckett Paper Co.	Hamilton, OH	IIa	160
Howard Paper Mills, Inc.	Urbana, OH	IIa	80
Howard Paper Mills, Inc.	Dayton, OH	IIa	125
Miami Paper Corp.	W. Carrollton, OH	IIa	100

OKLAHOMA

Company	Location	Mill Type	Production (TPD)
Weyerhauser Co.	Valliant, OK	Ik(Ib,Ic,Ie,If)	1500, 500

OREGON

Company	Location	Mill TYpe	Production (TPD)
American Can Co.	Halsery, OR	Ik(Ib,Ic)	340
Boise Cascade Corp.	Salem, OR	Ik(Ih, Ii)	255
Boise Cascade Corp.	St. Helens, OR	Ik(Ie, Ib,Ic)	600, 100
Concel Inc.	St. Helens, OR	Ik(Ib,Ic)	120
Crown Zellerbach Corp.	Clatskanie, Or	Ik(Ib,Ic, Ij	890, 325
Crown Zellerbach Corp.	Lebanon, OR	Ik(If, Ii)	105
Georgia-Pacific Corp.	Toledo, OR	Ik(Ie, If)	1100, 250
International Paper Co.	Gardiner, OR	Ie	520
Publisher Forest Products Co.	Newburg, OR	Ik(Ii, Ij)	250, 420
Publishers Forest Products Co.	Oregon City, OR	Ik(Ii, Ij)	180, 450, 60
Weyerhauser Co.	Springfield, OR	Ik(Ib,Ic, Ie)	1090
Williamette Industries	Albany, OR	Ik(Ie, If)	650, 200

PENNSYLVANIA

Company	Location	Mill Type	Production (TPD)
Appleton Papers Inc.	Roaring Springs, PA	Ik(Ib,Ic)	180, 25
Glatfelter Co.	Spring Grove, PA	Ik(Ib,Ic)	550
Hammermill Papers Group	Lock Haven, PA	IIa	530
Hammermill Paper Group,	Erie, PA	Id	420
Penntech Papers Inc.	Johnsonburg, PA	Ik(Ib,Ic)	180
Proctor&Gamble Paper Prod. Co.	Mehoopany, PA	Ik(Ih,Ii)	750

SOUTH CAROLINA

Company	Location	Mill Type	Production (TPD)
Bowater Carolina Co.	Catawba, S.C.	Ik(Ie, Ij, Ib,Ic)	860, 240, 150, 90
International Paper Co.	Georgetown, S.C.	Ik(Ib,Ic, Ie)	365, 1240
South Carolina Industries,Inc.	Florence, S.C.	Ie	1300
Westvaco Corp.	Charleston, S.C.	Ik(Ib,Ic, Ie)	2000

TENNESSEE

Company	Location	Mill Type	Production (TPD)
Bowater Southern Paper Co.	Calhoun, TN	Ik(Ij, Ib,Ic, Id)	500, 8230, 520, 820

TEXAS

Company	Location	Mill Type	Prodction (TPD)
Champion International Corp.	Pasadena, TX	Ik(Ib,Ic)	800
International Paper Co.	Texarkana, TX	Ik(Ib,Ic)	1290
Owens-Illinois Inc.	Orange, TX	Ie	1175
St. Regis Paper Co.	Lufkin, TX	Ik(Ib,Ic, Ie, Ij)	400, 830
South Land Paper Mills Inc.	Houston, TX	Ik(Ib,Ic Ie, Ij)	350, 300, 800
Temple-Eastex Inc.	Evadale, TX	Ik(Ib,Ic)	1500

WASHINGTON

Company	Location	Mill Type	Production (TPD)
Boise Cascade Corp.	Wallula, WA	Ik(If, Ib,Ic)	465, 280
Crown Zellerbach Corp.	Camas, WA	Ik(Ib,Ic) Ii, Ie)	810, 440
Crown Zellerbach Corp.	Port Townsend, WA	Ie	475
Georgia-Pacific Corp.	Bellingham, WA	Ik(Ih, Ii)	500
ITT Rayonier Inc.	Hoquiam, WA	Ik(Ih, Ii)	500
ITT Rayonier Inc.	Port Angeles, WA	Ik(Ib,Ic, Ih, Ii)	500
Longview Fibre Co.	Longview, WA	Ik(Ib,Ic) Ie, If)	1650, 220, 500
St. Regis Paper Co.	Tacoma, WA	Ik(Ib,Ic, Ie)	220, 820
Scot Paper Co.	Everett, WA	Ik(Ii, Ij)	450
Weyerhaeuser Co.	Everett, WA	Ik(Ib,Ic, Ij)	385, 330
Weyerhaeuser Co.	Longview, WA	Ik(Ib,Ic, Ie, If)	750

WISCONSIN

Company	Location	Mill Type	Production (TPD)
American Can Co.	Gr. Bay, WI	Ik(Ih, Ii)	150
Badger Paper Mills Inc.	Peshtigo, WI	Ik(Ih, Ii)	150
Consolidated Papers Inc.	Appleton, WI	Ik(Ih, Ii)	140
Consolidated Papers Inc.	Wisconsin Rapids, WI	Ik(Ib,Ic, Ij	5, 36, 92, 572
Flambeau Paper Corp.	Park Falls, WI	Ik(Ih, Ii)	110
Fox Riber Paper Co.	Appleton, WI	IIa	50
Gilbert Paper Co.	Menasha, WI	IIa	300, 78
Gr. Bay Packaging Inc.	Gr. Bay, WI	Ik(Ie, II, If)	495, 150
Mosinee Paper Corp.	Mosinee, WI	Ik(Ib,Ic, Ie)	195
Nekoosa Paper Inc.	Nekoosa, WI	Ik(Ib,Ic)	470
Nekoosa Paper Inc.	Port Edwards, WI	Ik(Ih, Ii)	385
Procter & Gamble Paper Prod.Co.	Gr. Bay, WI	Ik(Ih, Ii)	360
Rhinelander Paper Co. Inc.	Rhinelander, WI	Ik(Ii, Ih, Ii)	78, 80, 15
Thilmary Pulp &Paper CO.	Kaukauna, WI	Ie	400
Wausau Paper Mills Co.	Brokaw, WI	Ik(Ih, Ii,Ii)	190
Weyerhaeuser Co.	Rothschild, WI	Ik(Ih, Ii)	210
Whiting Paper Co.	Menasha, WI	IIa	20

VIRGINIA

Company	Location	Mill Type	Production (TPD)
The Chesapeake Corp. of Va.	West Point, VA	Ik(Ib,Ic, Ie)	1150, 300
Continental Forest Inds.	Hopewell, VA	Ik(Ie)	1100
Owens-Illinois Inc.	Big Island, VA	Ik(If)	575, 125
Union Camp Corp.	Franklin, VA	Ik(Ib,Ic, Ie)	1800, 300
Virginia Fibre Corp.	Riverville, VA	Ik(If)	600, 100
Westvaco Corp.	Covington, VA	Ik(Ib,Ic,If)	1100, 300

VERMONT

Company	Location	Mill Type	Production (TPD)
Georgia Pacific Corp.	Gilman, VT	IIa	200

A-3034

An Assessment of the Potential for Water Reuse in the Pulp and Paper Industry

QUARTERLY PROGRESS REPORT
March 1982 to May 1982

Prepared for

The Office of Water Research and Technology
United States Department of the Interior
Under Research Grant #14-34-0001-1468
Starting Date: September 1, 1981

Prepared by
Georgia Institute of Technology
Engineering Experiment Station
Atlanta, Georgia 30332

June 1982

TABLE OF CONTENTS

	Page
INTRODUCTION	1
PLANT DATA ACQUISITION	1
Selection of Mills for Visitation	1
Progress-to-Date	2
Contact Procedure	4
Survey Format	5
Limitations on Data Acquisition	6
Preliminary Survey Results	8
COMPUTER MODELING	12
FUTURE PLANS	18
APPENDICES: I. Survey Package Mailed to Mill	I-1
II. Follow-up Letter of Appreciation	II-1
III. Fundamental Data on Mills Visited	III-1

INTRODUCTION

This report highlights the technical progress made from March 1 through May 31 in evaluating the potential for water reuse in the pulp and paper industry. The emphasis of this quarter's work has been:

- o Initiating mill visits to acquire specific data on water usage, reuse, and limitations to reuse.
- o Completing and debugging of the computer model for optimization studies.
- o Operating the computer model on mill data collected in the survey to verify its validity.

PLANT DATA ACQUISITION

Selection of Mills for Visitation

Based on Georgia Tech's close relations with several mills in the State of Georgia, three such mills were initially selected for contact. These mills provided the study group with an opportunity to gain experience and to refine the interviewing procedure in terms of thoroughness, expedient use of interview time, and adaptability of data collected in terms of computer modeling optimization. Furthermore, previous study work with these mills in the area of fresh water usage enabled the project team to correlate newly acquired data with that performed earlier for inconsistencies.

Subsequent plant selections were based on a variety of factors including:

- o Mill Category (Dissolving kraft, unbleached kraft, sulfite, etc.)

- Current water usage (gallons per ton)
- Water reuse performance (above average, average, below average)
- Fresh water source
- Effluent Discharge
- Mill production rate
- Mill Location

The intent of this selection process has been to assemble the broadest cross sections of mill processes that comprise the categories to be studied. Surveys of good, average, and poor water reusers in each category are being performed to accummulate data regarding the motivations behind various plants having various reuse rates.

Progress-to-Date

At present, seven plants have been audited. All of these plants are located in the South Atlantic-Gulf water resource region and use variations of the kraft pulping process. The actual categories of mills audited were as follows:

1 Market Bleached Kraft (Ib)
3 BCT Bleached Kraft (Ic)
1 Alkaline Fine (Id)
2 Unbleached Kraft (Ie)

The paper manufacturing industry is a heavy user of fresh water in the South-Atlantic-Gulf Region, accounting for approximately 2.0 bgd (25%) of the withdrawals. By the year 2000, this region is projected to become the largest manufacturing sector in both water withdrawals and consumption. Also, the paper industry is projected to be the largest manufacturing water user within this region and for the nation as a whole. Major factors contributing to the increase of the paper industry's water usage in relation to other industrial sectors include high consumption rates, production of wastewaters that are less recyclable, and steady rise in production capacity. Because the kraft process is so dominate in terms of total fresh water consumption in the U.S., this group has proven to be an excellent choice for beginning to acquire data, and analyze potentials for increased water reuse. The plants surveyed thus far have been most cooperative in not only responding to our survey questions but also in assisting us in learning the various limitations they face regarding water reuse.

To our surprise, three of the plants have shown very compelling motivations for water reuse and are thus very active with water conservation/discharge reduction projects. Details of this are covered in the Preliminary Results section of this report.

The survey form used to uniformly collect mill data has undergone an evolution since it was just developed. Appendix I shows the final survey form which is the product of three revisions. The revisions were necessary to tailor the survey to accommodate sub-process water reuse evaluations and computer modeling. Also, qualitative questions have been expanded to aid the team in verifying those constraints which inhibit further water reuse.

With regard to the computer model, the study team has inputted actual data from two mills to attempt a water balance. Since each mill has a very unique and complex water system, only major flow routes can be modeled. This technique of modeling existing plant water systems does provide some degree of error in the computer runs. However, the degree of error has proven to be less than 5-10% on initial runs.

Contact Procedure

The survey form consists of seven pages of questions, thus it is somewhat intimidating to the respondent. This problem is resolved by our technique of presenting it. The survey form, along with a congenial cover letter (See Appendix I), is first mailed to a selected plant site approximately three weeks prior to the planned audit. Generally, the package is mailed to a high ranking official such as a Technical Director, Vice President of Tech Affairs, or Plant Director. The cover letter introduces the study, study team, and our intent. It directs the potential respondent to the attached questionnaire merely to indicate the type of questions for which information will be acquired. About one week after the package is mailed to a mill, a follow-up telephone call is made to discuss the package, answer any questions, and to formally request a plant visit. Upon giving permission for the visit, the plant usually hands the package to a lower ranking person such as a manager of the water and waste systems or production manager who is requested to gather the data (especially for the questions requiring numerical responses). This "homework" pays off in making a normal audit require only about 3 hours of interview time during the mill visit. Approximately half of the visits conducted to date have also included a tour of the plant to obtain a detail of process flows for computer modeling. This practice is employed primarily in those plants who are low or high in fresh water usage or who employ a unique process.

As the collected survey data is inputted to the computer model, deficiencies are sometimes found which required follow-up contacts. The necessary information is usually obtainable by a telephone call and subsequently added to the survey form.

After a survey, the participating paper mill is appropriately mailed a note to express our appreciation for providing us with the survey information An example of this note of appreciation is attached in Appendix II.

Presently, plant cooperation has been excellent. Only one plant of the twelve who have been solicited has declined because major process changes were currently being performed, and therefore water system data was not available. When visited, plants have in turn answered most of the questions asked in a fairly complete fashion.

Survey Format

The plant survey is divided into two basic sections. The first section entitled, Fundamental Mill Data, requests basic numerical process information required to make plant modeling possible. This information includes specific units of input and output, thus setting limitations for the various sub-processes throughout the plant.

The second section titled, Survey Questions - Production and Process Controls, contains a set of questions designed to acquire specific internal mill process information with regard to primary material flow routes. These questions are both qualitative and quantitative in that they facilitate the development of a basic water balance within the mill departments. This section also yields the anticipated restrictions of further water reuse and identifies planned activities and external forces which may modify current mill operations and water usage practices.

The current survey form is expected to undergo further minor revisions. When this occurs, previously surveyed plant data files will be updated to the newly revised survey form. This requires some "back tracking" in data acquisition when the newly acquired information is not currently on file, but insures that a uniform data bank is maintained from which to draw analogies and comparisons. At present, the survey form has not been exercised on mill types other than kraft processes, thus minor revisions are anticipated as the study team surveys other processes in the immediate future.

It must be noted that questions in the survey are tempered so that optimization iterations can be made without the aid of the GEMS computer program if necessary. This degree of safety has been employed in the event that the computer model proves unable to provide useful data in all or any portion of the optimization endeavors. This policy of not "banking" on the computer program also yields a strengthening of the optimization endeavors by enabling the reseachers to do some hand calculated steps to verify that computer outputs are accurate and realistic. Also internal reviews of the computer model are carried out to assure that the internal processes and subprocesses depict actual mill conditions per the data collected during the survey.

Limitations on Data Acquisition

As expected, quantitative information needed for modeling is not always available from the mills. This is generally a product of deficient internal process metering and not on the mill's willingness to provide such information. The unbleached kraft mills are particularly prone to not knowing water flows in many of their specific processes and subprocesses. Participants have offered design conditions according to mill blueprints, but admit that these blueprints are frequently out of date and do not reflect many of the recent process changes which have subsequently occurred.

All of the mills thus far have been able to provide reasonably accurate information in at least some areas of their operation. The deficit information has typically been found by calculations which use stock consistencies on specific pieces of equipment. For example, if total fresh water consumption on the paper machine is not known, but the Fourdrinier headbox consistency is known, then a determination of water demand is possible by knowing the production output of the machine. Modeling with the calculated numbers plus numbers provided by a mill has yielded a total mill water consumption that matches closely with total effluent volumes which is always known. Organizing the process flows on the GEMS model allows a check to verify calculated quantities. The final output can then be reviewed with plant personnel by telephone to verify if estimations closely match what they expect. This technique has proven effective thus far because unknown quantities have been few and enough information from the plant audits has been obtained to satisfactorily verify values that were generated through in-house calculation. It is conceivable that a particular plant audit will not yield enough information to model with a satisfactory degree of confidence due to the large number of processing unknowns. But, the chances for such seem to be remote because of the amount of internal control employed by the surveyed plants to meet environmental controls on effluent discharges.

With regard to data being withheld, only in one case has the problem of proprietary information limited the amount of data that has been collected in the field visits. In this case, the Technical Director indicated that he would have to check and see if some of the information could be made available. He subsequently mailed specific responses to several questions after obtaining approval from upper management. However, several mills would not yield cost information regarding fresh water acquisition and treatment. Some simply indicated that they did not have accurate numbers. Therefore, the availability of water and water treatment costs is expected to be severely limited for use in reviewing limitations on increased water reuse.

There has been some difficulty encountered regarding those mills located in regions of plentiful water supplies which have substantial seasonal fluctuation in water consumption. Generally, these mills use greater amounts of water in the warm summer months for cooling purposes and subsequently use much of this water elsewhere in production operations on a once-through basis. This yields a substantial reduction in water reuse during periods of heavy cooling loads. In order to deal with this, winter water reuse figures are being considered typical for such mills with a note made that increased summer usage is common due to heavy cooling loads.

Preliminary Survey Results

Currently, seven paper/pulp mills have been surveyed. A copy of the fundamental mill data sheets from these surveys is included in Appendix III. All of these plants are located in the States of Georgia and Alabama where fresh water supply is generally accepted as plentiful for industry. It is interesting to note that published information in pulp and paper directories is generally not as complete or accurate as one might expect. The audits conducted thus far have not shown any major deviations from currently available information, but minor inconsistencies especially in production and consumption figures are quite common.

Another observation from the initial surveys is that many plants do not extensively utilize internal metering to track water consumption on a departmental basis. Many plants rely on only one or two metering devices with no refined breakdown of fresh water usage throughout the plant aside from material balance blueprints. To date, the project team has been able to determine internal fresh water distribution by utilizing metered flows together with general plant layout and stock consistencies at key points in the process as noted earlier. Those values which are determined by this method can then be checked with mill "design" flows for comparative purposes.

The study team has been able to determine that a number of the plants listed in Table 1 do have existing incentives for water conservation and reuse even though fresh water is considered plentiful in the states in which they are located. This has proven interesting because most paper/pulp mills find it difficult to quantify savings on a net reduction of fresh water usage, thus it is difficult for projects to be implemented on the basis of overall cost reduction. The most advanced plant in fresh water usage reduction is the unbleached kraft mill "B" as labeled in Table 1. Effluent treatment cost savings were the primary motivation for the high degree of water reuse in this mill.

This plant operates a joint treatment facility with the neighboring city, thus waste treatment cost is based on discharge volume as well as more traditional cost determining methods such as B.O.D. and total suspended solids. As a result of this arrangement, the plant has substantially limited waste discharge volume and subsequently observed a corresponding reduction in fresh water consumption. The initial modification of mill process was for reduced effluent volume and was completed by the fact that there developed a problem with the treatment plant being unable to meet discharge regulations. But, the project has subsequently been successfully implemented and now shows an unexpected savings based on the recovery of low temperature thermal losses. Reducing the effluent discharge volume rate through significant water reuse has resulted in a net reduction in plant energy requirements.

Based on general industry statistics, it is believed that plant "B" employs one of the best degrees of water reuse for its given production category. This is supported by results that were obtained from preliminary water reuse efforts at mill "C". Modifications made to increase water reuse by plants "C" and "F" have been a consequence of long term efforts to reduce fluctuations in fresh water quality.

TABLE 1

PRELIMINARY DATA RESULTS

PLANT	PLANT TYPE	PRODUCTION TONNAGE (TPD)	UNIT WATER CONSUMPTION (GAL/ADT)	PROCESS WATER SOURCE	LIMITATIONS OF FRESH WATER SUPPLY
"A"	Unbleached Kraft	1800	10,700	River	None
"B"	Unbleached Kraft	1400*	6,000	River	Yes**
"C"	Bleached Kraft	1700	32,900	Wells	Yes
"D"	Bleached Kraft	600	33,000	River	No
"E"	Bleached Kraft	550	36,000	River	No
"F"	Bleached Kraft	1000	27,300	River	Yes
"G"	Bleached Kraft	1000	37,000	River	No

*900 Virgin Pine, 400 Recycle
**Limitation on effluent discharge volume

All three of these plants have initiated steps to reduce fresh water consumption and have identified incentives such as energy conservation to justify further process modifications. It is hoped that quantitative data of these incentives can be made available so that this information can be published in the final report.

Two sub-processes in mills visited to date appear to be the primary targets for water reuse. These are the brown stock screening-decker system and the paper/pulp forming machine. Both of these processes have historically utilized large quantities of fresh water for white water system purge. Thus, the addition of fresh water in these processes reduces the cyclic buildup of minerals, corrosives, and pulp fines. As increased reuse in these processes is employed, chemical additives and filtration are required. The introduction of additives have had an impact on pulp quality, scaling, and production rates. Plant "B" has indicated that this criteria is of principal interest as it limits further water reuse at present.

To date, the problem of thermal buildup has not been indicated as a limitaton on increased water reuse. All seven mills have indicated that this criteria has not yielded any problems. In fact, some thermal buildup is considered somewhat attractive at present since it promises to eliminate selected steam heating (primarily in the wire pit). Increased corrosion also has not been mentioned as a limiting factor associated with higher white water temperatures associated with greater water reuse. Yet published reports indicate this to be important criteria of consideration.

Another observation was made based on the audits. Most plants visited are seeing the affects of the present economic recession. This means that plant improvements are limited to those of high paybacks due to the limited availability of funding for such. Unfortunately, this state of affairs often puts water reusage projects off in favor of projects of higher or of more measurable returns. Furthermore, water reuse projects often are considered process innovations with some risk to pulp quality. This factor has made it difficult to sell good projects to upper management for internal funding. Even with the economic climate as is, only one plant has indicated a planned interval shutdown due to a soft market and high inventories.

COMPUTER MODELING

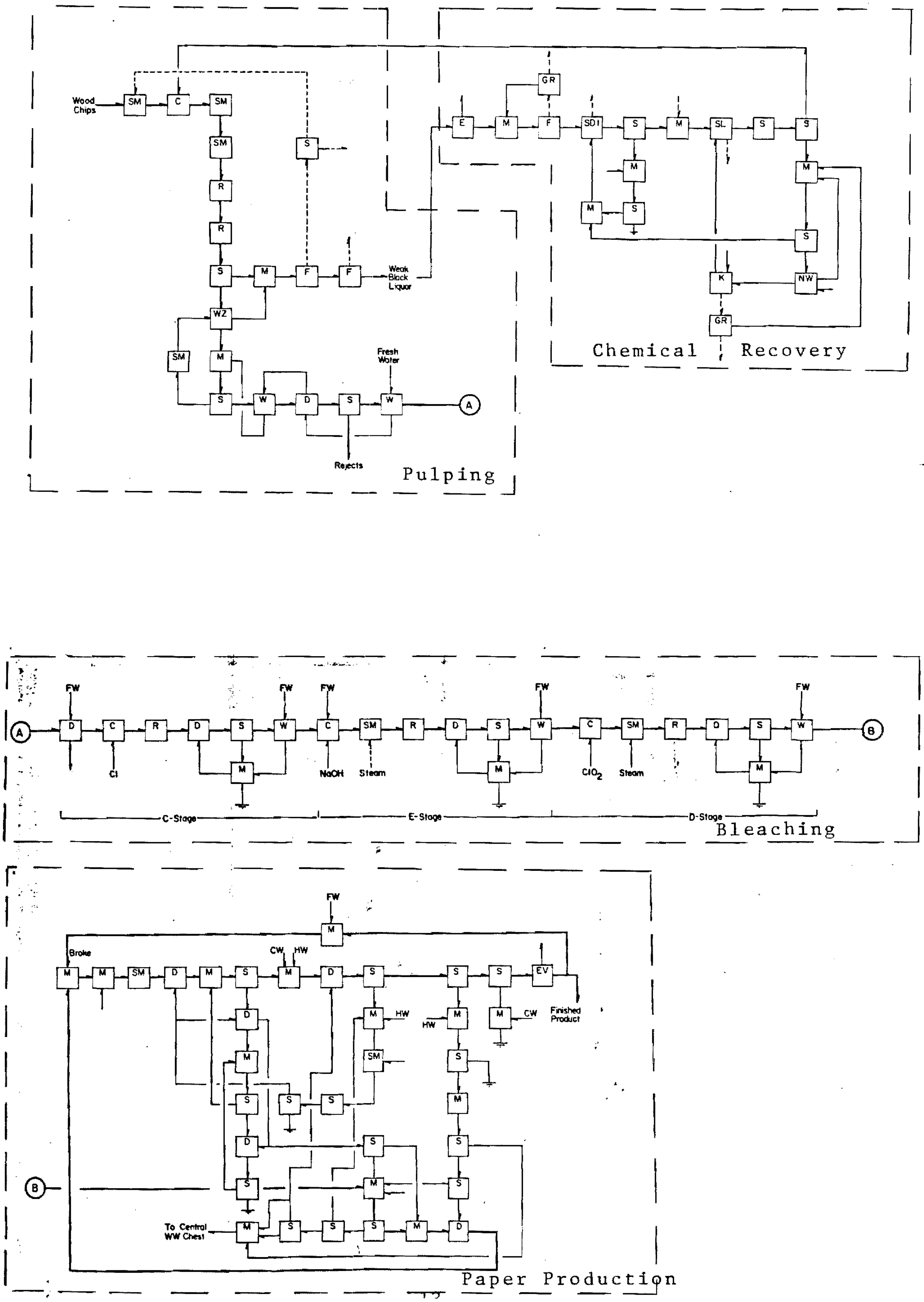
During the past quarter, work with the GEMS computer model has progressed to the point of inputting actual mill data into the program. Preliminary quantitative results have been obtained for two unbleached kraft mills which have produced results for total influent within 12% of actual mill numbers.

The flow diagram being used in the computer model is shown in Figure 1. For unbleached mills, the bleaching section is simply deleted. The chemical recovery module has recently been added to complete the basic modeling of all major sub-process in the pulp and paper operation.

Several problems have been encountered in using the GEMs model. One area of principal concern is difficulty in acquiring the necessary detail in input data. In using a model of this nature, large amounts of detailed data at very specific points in the pulp flow have to be known to truly make the model representative. Examples are wash water flows over checks, percentage rejects from screenings, temperatures across heat exchange equipment, and many others. This data is often too copious to gather during a plant visit, and much of it is unknown to plant personnel anyway. To overcome this problem, as mentioned earlier, data has been derived from other numbers more easily obtained from the mills or found in textbooks and known to be reliable. Both

Figure 1

General Flow Diagram of Pulp and Paper Production Processes per GEMS



methods have been used to some extent in computer runs made this quarter.

A second major area of concern involves defining a typical pulp mill flow diagram. In one of the plants modeled, two paper machines were operated off one pulping section, with one paper machine utilizing principally recycled water and the second paper machine utilizing part recycle water and part fresh. Purge water for the paper machines were white water recycle with fresh water make-up. Thus, the paper machine with 100% recycle actually received make-up water from the other paper machine. Preliminary modeling of this configuration was performed utilizing one paper machine model which contained an overall mass balance that accounted for both actual paper machines. The results of this simplification yielded very close results to the overall water balance of the actual paper machines. This technique was performed to test the validity of considering one paper machine model for simplification when in reality the actual processes utilized two paper machines operating in parallel of each other, and appears to be valid for the specific mills utilized to date. At present, the utilization of one paper machine model is being studied to see if it offers the flexibility in water reuse optimization iterations.

It is also interesting to note that the mill discussed above had strong economic pressures to minimize effluent volume. As a consequence of this economic incentive, fresh water consumption per unit of production for this plant is considered one of the lowest in the country for kraft mills. With this mill's recent experience in increased use of recycle waters, it has offered a wealth of information concerning the technological limitations encountered is further reuse.

Results of the two mills modeled to date have served to verify that the GEMS model is providing reasonably accurate results. In the two cases examined, verification was performed in two areas: 1) verifying that the pulp flow though the plant met the material balance at the proper effluent points, and 2) verifying that water usage was qualitatively acceptable. With regard to detailed water flow verification, less significance was placed on quantitative verification because the additional effort needed to refine the model to reflect individual mill water flows was considered excessive.

In the verification of pulp flow, the two mills studied matched the actual mill flow patterns in both overall effluent and in the pulp product stream. With respect to overall effluent, numbers matched to one decimal; less than 10% for an 1800 tpd plant and similar accuracy was found for a 2300 ton per day plant. The product pulp stream (#68 in Figure 2) showed consistencies for both mills of 4% which compared favorably with the 6% consistency reported at both mills.

In the verification of overall water usage, influent into the 2300 tpd plant was checked. This item was more a verification of the initial program assumption than a check of actual computer accuracy. Flow rates into the plants given as "reasonable" in the GEMS literature were scaled up to the particular plant in question. Results using this very crude method were encouraging. For the unbleached kraft 2300 tpd plant actual influent from mill data was 3.5 million gals/day. Based on computer scaling, the influent was 3.1 millions gals/day. This level of agreement seems to indicate that with only minor refinements, the computer model is accurate. Additional data will be needed on actual water influent of individual streams at these mills to check the accuracy of the scaled up model.

One additional limitation of the model has been identified in the area of water usage calculations. The model seems only useful in doing material and energy balances on streams that make physical contact with the pulp flow through the process. This limitation does

Figure 2

Computer Printout for 2300 tpd Mill Using GEMS Model

STREAM VARIABLES

	LIQUOR	PULP	TEMP	DIS. SOLIDS
7	302.0271	.3284445E-01	49.35509	.1567705E-01
8	303.0271	.3273607E-01	49.26180	.1212264
9	1.000000	0.	10.00000	52.00000
10	303.0271	.3273607E-01	48.70180	.1212264
11	2847.566	.5025126E-02	49.86052	.6292554E-01
12	1132.902	.3086820E-02	49.99120	.5641766E-01
13	3980.369	.4473489E-02	49.89769	.6107305E-01
14	3883.226	.4126858E-02	49.89769	.6107301E-01
15	97.14237	.1832994E-01	49.89769	.6107301E-01
16	1017.128	.3310926E-02	49.99018	.5646871E-01
17	771.3982	.1725051E-02	50.00000	.5598254E-01
18	147.5108	.3511851E-02	49.99825	.5606898E-01
19	1164.626	.3336373E-02	49.99120	.5641738E-01
20	4236.545	.1725071E-02	50.00000	.5598345E-01
21	4236.545	.1725071E-02	50.00000	.5598345E-01
22	1691.584	.1725051E-02	50.00000	.5598254E-01
23	51.72406	.1224820E-01	49.99120	.5641785E-01
24	159.7732	.3814495E-02	49.99825	.5606598E-01
25	12.26238	.7455138E-02	49.99825	.5606898E-01
26	38.10000	0.	54.44000	0.
27	3984.826	.4021636E-02	50.01335	.5951082E-01
28	63.50000	0.	54.44000	0.
29	3991.461	.4016064E-02	50.00877	.5948112E-01
30	400.0000	.6693551E-03	47.25654	.3861931E-01
31	54.94532	.2500000	50.00877	.5948112E-01
32	3936.515	.1843449E-02	50.00877	.5948112E-01
33	212.2500	0.	54.44000	0.
34	4259.245	.1725071E-02	50.18786	.5598343E-01
35	80.50000	.6693551E-03	47.25654	.3861931E-01
36	22.37720	2828.000	0.	0.
37	4259.245	.1725071E-02	50.00000	.5598346E-01
38	22.70000	.1725071E-02	50.00000	.5598346E-01
40	10.00000	.1725051E-02	50.00000	.5598254E-01
41	653.5491	.1725051E-02	50.00000	.5598254E-01
42	34.28750	0.	7.220000	0.
43	27.24000	0.	50.28035	.3607049E-02
44	304.7788	.3090000E-01	45.80000	.1000000E-01
45	999.8554	.1051209E-01	47.25654	.3861931E-01
46	89.10861	.1111111	47.25654	.3861931E-01
47	910.7468	.6693551E-03	47.25654	.3861931E-01
48	830.2468	.6693551E-03	47.25654	.3861931E-01
49	430.2468	.6693551E-03	47.25654	.3861931E-01
51	978.7824	.5631649E-03	47.73616	.3307041E-01
52	11.58072	.7543860	50.00877	.5948112E-01
53	23.36460	0.	50.00877	.5948112E-01
54	330.1756	0.	54.44000	0.
55	353.5402	0.	54.14716	.3930961E-02
56	.1000000E-02	0.	54.14716	.3930961E-02
57	353.5392	0.	54.14716	.3930961E-02
58	31.74770	0.	7.220000	0.
59	385.2869	0.	50.28035	.3607049E-02
60	385.2869	0.	50.28035	.3607049E-02
61	358.0469	0.	50.28035	.3607049E-02
62	99.10861	.1000741	47.52414	.4057125E-01
63	301.9902	.3284445E-01	49.35498	.1567423E-01
64	11.11896	.7857143	50.00877	.5948112E-01
65	.4617510	0.	50.00877	.5948112E-01
66	569.8600	0.	7.220000	0.
67	570.3218	0.	7.254642	.4815765E-04
68	.3640137	24.00000	66.00000	1.516878
70	663.5491	.1725051E-02	50.00000	.5598254E-01
71	593.3659	.6671685E-03	47.25737	.3862356E-01
72	155.1697	0.	50.28035	.3607049E-02
73	10.75495	760.0000	100.0000	0.

67 EOR 484

not permit cooling water streams, which do not contact the pulp flow, to be included in overall effluent calculations. This limitation should not be serious in that these streams typically are only indirectly involved in processing since they are only pumped through the process and back to the water source with only a temperature change.

In running the model, problems with thermal buildup have appeared as expected. In the flash tanks of the pulping group 2 (blocks labeled "F" - Figure 1) input temperature has exceeded its flash point. Also, in the evaporation section of the chemical recovery group (block labeled "E"), temperature of the weak black liquor has already exceeded the output temperature specified by the model in some runs. Such problems are favorable indication that the model is realistic. If these computer problems were not present, the computer would not be capable of recognizing this important limitation on water reuse.

One other limitation in the model that has been noted is its inability to iterate automatically towards an optimized solution. No real decision making can be built into the program to allow it to try different flow alternatives based on constraints input into it. Rather, the model is a simulation model which requires iterations to be done manually.

During the next quarter of the project, the major emphasis with the model will be to apply it to all mill types within the scope of the study, first to accurately model existing operations as indicated by the audits and then to begin optimizing water reuse within the constaints indicated by the study findings.

FUTURE PLANS

The study team has devoted the majority of its effort this past quarter to selecting, contacting, and surveying mills. Furthermore, much of the collected data has been inputted to the completed computer model. Plans for next quarter are to conclude the visitation of mills in the midwest, northwest, and northeastern United States representing of all ten mill types to which the study is now focused. In all, a total of 20 to 30 mills are expected to be interviewed and as already has been demonstrated, these mills are expected to provide not only useful data on the extent of current water reuse, but also the reasons behind the limited or restricted additional water reuse.

In addition to the mill visits, members of the team are planning to visit the Institute of Paper Chemistry in Appleton, WI, to collect data on water reuse studies already performed or currently underway. It is hoped that this valuable data resource will provide additional information regarding efforts to increase water recycle.

One further goal of the upcoming quarter is to solidify financial data which can be used to support or explain the failures of efforts toward additional water recycle. As mentioned in this report, the data collected thus far has been sketchy at best, and we anticipate a considerable effort will be needed to expand our knowledge in this area.

APPENDIX I

PACKAGE SENT TO MILLS

PLANT "A"

FUNDAMENTAL MILL DATA

Major Pulp Type Produced: Dissolving Kraft, Market Bleached Kraft, BCT Bleached Kraft, Alkaline Fine, Unbleached Kraft, Semi Chemical, Dissolving Sulfite, Papergrade Sulfite, Nonintegrated-Fine Papers

Current Production Rate 1800 TPD

Major Products & Percentages Unbleached Alkaline Pulp

Fiber Source & Type: Softwood 100 %, Hardwood ____ %, Secondary ____ %

Total Water Intake 15 MGD Indirect Cooling Water Intake ________ MGD

Freshwater Source River

Total Freshwater usage in each of the following areas. (Please specify units)

- Woodyard/woodroom
- Pulpmill - 2500 apm
- Bleachery
- Evaporation and recovery area
- Papermill
- Steam plant and utilities

How much water is lost to evaporation?

Is your plant ever production or quality limited due to a lack of adequate supply of fresh water? No - Water is plentiful.

What is the average steaming rate of the powerhouse? 725,000 #/hr

What percent of the boiler feedwater is make-up? 50%

PLANT "B"

FUNDAMENTAL MILL DATA

Major Pulp Type Produced: Dissolving Kraft, Market Bleached Kraft, BCT Bleached Kraft, Alkaline Fine, Unbleached Kraft, Semi Chemical, Dissolving Sulfite, Papergrade Sulfite, Nonintegrated-Fine Papers

Current Production Rate ______ TPD 900 TPD Virginia Pine 500 TPD Recycle (OCC)

Major Products & Percentages Board for corrugated boxes

Fiber Source & Type: Softwood 65%, Hardwood ___%, Secondary 35% Recycle %

Total Water Intake 8.5 MGD Indirect Cooling Water Intake 4.5 MGD

Freshwater Source River

*Total Freshwater usage in each of the following areas. (Please specify units) GPM

- Woodyard/woodroom Zero
- Pulpmill 2000
- Waste Pond 300
- Bleachery NA
- Evaporation and recovery area Combined with steam plant
- Papermill 4000**
- Steam plant and utilities 600

How much water is lost to evaporation? 1200 gal/ton

Is your plant ever production or quality limited due to a lack of adequate supply of fresh water? No

What is the average steaming rate of the powerhouse? 700,000 #/hr

What percent of the boiler feedwater is make-up? 42%

*Water usage in each department is in terms of "mill supply" which consists of 45% fresh water and 55% Reused water

**Two paper machines one utilizes mill supply water, other uses waste water from #1 machine

PLANT "C"*

FUNDAMENTAL MILL DATA

Major Pulp Type Produced: Dissolving Kraft, Market Bleached Kraft, BCT Bleached Kraft, Alkaline Fine, Unbleached Kraft, Semi Chemical, Dissolving Sulfite, Papergrade Sulfite, Nonintegrated-Fine Papers

Current Production Rate 1700 TPD

Major Products & Percentages

Fiber Source & Type: Softwood ___%, Hardwood ___%, Secondary ___%

Total Water Intake 56 MGD Indirect Cooling Water Intake 20-25 MGD

Freshwater Source Wells for process, river (saline) for cooling

Total Freshwater usage in each of the following areas. (Please specify units)

- Woodyard/woodroom
- Pulpmill 5.4 MGD
- Bleachery 35 MGD
- Evaporation and recovery area & steamplant 8.3 MGD (5.9 feedwater)
- Papermill 7 MGD
- Steam plant and utilities

How much water is lost to evaporation? ~ moisture input with wood and out with pulp

Is your plant ever production or quality limited due to a lack of adequate supply of fresh water? *Aquifar is getting more saline - possibly in future

What is the average steaming rate of the powerhouse? ~ 50%? #/hr

What percent of the boiler feedwater is make-up? ~ 50%

*Plant generates all of its bleaching chemicals from salt, salt cake, and caustic

PLANT "D"

FUNDAMENTAL MILL DATA

Major Pulp Type Produced: Dissolving Kraft, Market Bleached Kraft, BCT Bleached Kraft, Alkaline Fine, Unbleached Kraft, Semi Chemical, Dissolving Sulfite, Papergrade Sulfite, Nonintegrated-Fine Papers

Current Production Rate 600 TPD

Major Products & Percentages

Fiber Source & Type: Softwood 60 %, Hardwood 40 %, Secondary ____ %

Total Water Intake 20.0 MGD Indirect Cooling Water Intake ________ MGD

Freshwater Source River

Total Freshwater usage in each of the following areas. (Please specify units)

- Woodyard/woodroom
- Pulpmill
- Bleachery
- Evaporation and recovery area
- Papermill
- Steam plant and utilities

8.8 MGD: P.Hse, Digest, WBS, P.D.
Pulp Machine, Caust
3 MGD Paper maching

How much water is lost to evaporation? 54 gam on pulp dryers (excl. paper machine)

Is your plant ever production or quality limited due to a lack of adequate supply of fresh water? No

What is the average steaming rate of the powerhouse? 500,000 #/hr

What percent of the boiler feedwater is make-up? 50-55%

PLANT "E"

FUNDAMENTAL MILL DATA

Major Pulp Type Produced: Dissolving Kraft, Market Bleached Kraft, BCT Bleached Kraft, Alkaline Fine, Unbleached Kraft, Semi Chemical, Dissolving Sulfite, Papergrade Sulfite, Nonintegrated-Fine Papers

Current Production Rate 550 TPD

Major Products & Percentages

Fiber Source & Type: Softwood 40 %, Hardwood 60 %, Secondary ____ %

Total Water Intake 20* MGD Indirect Cooling Water Intake Cooling water enters ~~process~~ MGD

Freshwater Source River

Total Freshwater usage in each of the following areas. (Please specify units)

- Woodyard/woodroom 1/2 raw water from river
- Pulpmill
- Bleachery
- Evaporation and recovery area
- Papermill
- Steam plant and utilities

How much water is lost to evaporation?

Is your plant ever production or quality limited due to a lack of adequate supply of fresh water? No

What is the average steaming rate of the powerhouse? ________ #/hr

What percent of the boiler feedwater is make-up?

*Winter usage, Summer is 21.5 due to cooling

PLANT "F"

FUNDAMENTAL MILL DATA

Major Pulp Type Produced: Dissolving Kraft, Market Bleached Kraft, BCT Bleached Kraft, Alkaline Fine, Unbleached Kraft, Semi Chemical, Dissolving Sulfite, Papergrade Sulfite, Nonintegrated-Fine Papers

Current Production Rate 1000 TPD

Major Products & Percentages

Fiber Source & Type: Softwood 4dys/wk %, Hardwood 3dys/wk %, Secondary ____ %

Total Water Intake 27.3 MGD Indirect Cooling Water Intake ________ MGD

Freshwater Source

Total Freshwater usage in each of the following areas. (Please specify units)

- Woodyard/woodroom
- Pulpmill 5.3 MGD
- Bleachery 3.6 MGD
- Evaporation and recovery area P.Hse 12.8 MGD
- Papermill 1.25
- Steam plant and utilities
  Misc. & Caust 4.35

How much water is lost to evaporation? 700,000 APD

Is your plant ever production or quality limited due to a lack of adequate supply of fresh water? No*

What is the average steaming rate of the powerhouse? 750,000 #/hr

What percent of the boiler feedwater is make-up? 35%

*Low river -- low water quality in

PLANT "G"

FUNDAMENTAL MILL DATA

Major Pulp Type Produced: Dissolving Kraft, Market Bleached Kraft, BCT Bleached Kraft, Alkaline Fine, Unbleached Kraft, Semi Chemical, Dissolving Sulfite, Papergrade Sulfite, Nonintegrated-Fine Papers

Current Production Rate 1000 TPD

Major Products & Percentages 900 TPD paper board, 100 TPD Absorbent, packageing, etc.

Fiber Source & Type: Softwood ____ %, Hardwood ____ %, Secondary ____ %

Total Water Intake 37 MGD Indirect Cooling Water Intake ________ MGD

Freshwater Source

Total Freshwater usage in each of the following areas. (Please specify units)

- Woodyard/woodroom
- Pulpmill
- Bleachery
- Evaporation and recovery area
- Papermill
- Steam plant and utilities

How much water is lost to evaporation?

Is your plant ever production or quality limited due to a lack of adequate supply of fresh water?

What is the average steaming rate of the powerhouse? ________________ #/hr

What percent of the boiler feedwater is make-up?

APPENDIX II

FOLLOWUP LETTER OF APPRECIATION

ENGINEERING EXPERIMENT STATION
Georgia Institute of Technology
A Unit of the University System of Georgia
Atlanta, Georgia 30332

April 22, 1982

Mr. Jonathan Smith
Brunswick Pulp and Paper
P.O. Box 1438
Brunswick, GA 31520

Sample

Dear Mr. Smith:

We want to thank you for your cooperation and assistance in helping us to gather information on the potential for water reuse in the pulp and paper industry. The data recently gathered during our visit to your facilities helped us to understand both the extent to which you are currently reusing water and to identify those constraints (technological and economic) affecting your additional reuse of water.

Let me assure you that this data will be treated in confidence and will not be released in any manner that would identify its source unless we specifically receive your approval to do so.

Should we have further questions regarding your operations, we hope you will not mind our calling you. In the meantime, again thank you for your help.

Sincerely,

J. Craig Wyvill
Project Director
Technology Applications Laboratory

JCW/pr

APPENDIX III

FUNDAMENTAL DATA ON MILLS VISITED

ENGINEERING EXPERIMENT STATION
Georgia Institute of Technology
A Unit of the University System of Georgia
Atlanta, Georgia 30332

April 22, 1982

Mr. James W. Malone
Mill Manager
American Can Company
Naheola Mill
Box 315
Butler, AL 36904

Sample

Dear Mr. Malone:

In September 1981, the Georgia Tech Engineering Experiment Station received a grant from the Office of Water Research and Technology (U.S. Department of the Interior) to study the potential for water reuse in the pulp and paper industry. A summary of the project is attached.

An important feature of the proposed work plan is the visitation of mill sites. These visits are designed to help gather data on the current extent of water reuse in mills across the country and to identify constraints (both technological and financial) preventing further water reuse.

We would like the opportunity to visit your mill and discuss reuse as it relates to our study. To provide you with a better understanding of the types of data we would like to collect, I have attached a copy of our survey form. We will use this form on our visit. Let me stress that it is our intention to treat any data collected from your mill in the strictest of confidence. The data will be used to assemble a data base and will not be published in a manner which identifies its source, unless prior approval is obtained.

We hope you will assist us in conducting this important research. We will be in touch by phone in a few days to discuss trip arrangements. In the meantime, if I can answer any questions regarding the study or our information needs, please feel free to contact me at (404) 894-3623.

Sincerely,

J. Craig Wyvill
Project Director
Technology Applications Laboratory

PROJECT SUMMARY

1. TITLE - An Assessment of the Potential for Water Reuse in the Pulp and Paper Industry

2. SPONSOR - Office of Water Research and Technology - U. S. Department of the Interior, Washington, D.C. 20240 — PROJ. MGR. Robert Madancy (202) 343-6481

RESEARCHER - Engineering Experiment Station (TAL) - Georgia Institute of Technology, Atlanta, Georgia 30332 — PROJ. DIRECTOR J. Craig Wyvill (404) 894-3623

3. PROJECT DURATION - 1 year and 3 months

4. WATER RELATED PROBLEM - The need for water reuse in the pulp and paper industry, the third largest industrial user of water in the nation, is indicated by rapidly increasing restrictions on site location due to inadequate supplies of clean water and to insufficient stream assimulative capacities to handle normal waste discharges. In 1975, this industry used nearly 8.5 billion gallons of water each day. Industry growth is expected to place even heavier and more difficult demands on water supply.

So intense is the problem that this sector is listed by OWRT as needing immediate studies to assess the magnitude of wastewater reuse that may be required in the future to augment existing water sources. The proposed effort is designed to fully identify the current extent of water reuse in the industry, the future potential for additional water reuse, and assess barriers to this increased reuse. The study is designed to provide a working document summarizing the problem and identifying possible ways to deal with it.

5. CONTRIBUTION TO PROBLEM SOLUTION - By outlining the demands for water in the pulp and paper industry and identifying both the current and potential reuse of water to reduce the need for meeting this demand through fresh water withdrawal from ground and surface sources, this study is intended to provide both government and industry planners and decision makers essential information about the possible courses of action that can be taken to assure continued growth is achievable by this important industrial sector.

6. OBJECTIVES - The primary objective of the proposed research is to characterize water usage patterns in the pulp and paper industry and identify opportunities for increased water reuse. Implicit in this objective is the evaluation of reuse on both a regional and national level. The study will focus on barriers to reuse and identify where additional research should be conducted to overcome these barriers.

7. APPROACH - The approach to be used in performing the proposed effort will entail first assembling data on the industry through a literature survey of government and indusry sources including information maintained by technical organizations associated with this industrial sector. The data will then be used to characterize the industry and its processes. At this point, a systems approach will be used to thoroughly evaluate the water demands and requirements of processes and subprocesses common to production systems. Major processes will be subdivided into functional subsystems and individual proces water savings evaluated on the basis of substituting alternative subprocesses

or the addition of water treatment and recycle systems. Barriers to reuse in the various subsystems can then be thoroughly determined as well. Finally, by reassembling subprocesses into their major process catagories, an overall assessment of the full potential for reuse in the industry can be made. This assessment will be performed on both a regional basis and national basis and will include projections to the year 2000.

8. RESULTS USERS - This study will center on the primary grouping of the pulp and paper industry, namely the pulp, paper, and paper board sectors (SIC -2611, -2621, -2631). Consequently, the results will be useful throughout this industry. Industry and government planners are expected to utilize this information in evaluating actions to promote growth in the industry, and educational and trade institutions are expected use this information in fostering effective water usage.

FUNDAMENTAL MILL DATA

Major Pulp Type Produced: Dissolving Kraft, Market Bleached Kraft, BCT Bleached Kraft, Alkaline Fine, Unbleached Kraft, Semi Chemical, Dissolving Sulfite, Papergrade Sulfite, Nonintegrated-Fine Papers

Current Production Rate ____________ TPD

Major Products & Percentages

Fiber Source & Type: Softwood____%, Hardwood ____%, Secondary____%

Total Water Intake __________MGD Indirect Cooling Water Intake ________MGD

Freshwater Source

Total Freshwater usage in each of the following areas. (Please specify units)

- Woodyard/woodroom
- Pulpmill
- Bleachery
- Evaporation and recovery area
- Papermill
- Steam plant and utilities

How much water is lost to evaporation?

Is your plant ever production or quality limited due to a lack of adequate supply of fresh water?

What is the average steaming rate of the powerhouse? ________________ #/hr

What percent of the boiler feedwater is make-up?

SURVEY QUESTIONS

Production Process Controls

1. Woodyard/Woodroom

a. Close-up or dry woodyard and barking operations

b. Wood flumes or dry conveyors

2. Pulp Mill

a. Reuse relief and blow condensates

b. Reduced groundwood thickener overflow

c. Spill collection utilized

d. Condensates from cooking reused or sewered

3. Washers and Screen Room

a. How many washer stages

b. Fresh water utilized on last brown stock washer

c. Fresh water utilized on decker

d. Decker filtrate recycled

e. Any fresh water used in cleaner white water system

Survey Questions (continued)

4. Bleaching

a. Countercurrent or jump stage washing

b. Caustic extract filtrate reused

c. Points of application and flow rates of fresh water utilized for washing

d. Spill collection system

5. Evaporation and Recovery Areas

a. Condensate recycled

b. Boil out tank

c. Neutralize spend sulfite liquor

d. Segregated cooling water

e. Spill collection

Survey Questions (continued)

6. Liquor Preparation Area

a. Green liquor dregs filter

b. Fresh water utilized or dregs filter

c. Fresh water utilized for lime mud washing

d. Fresh water to kiln scrubbers

e. Spill collection

f. Spare tank

7. Papermill

a. Spill Collection on paper machine

b. Fresh water applications points and flow rates on machine

c. Saveall system

d. High pressure showers for wire felt cleaning

e. White water use for vacuum pump seal water

f. Paper machine white water shower wire and felt cleaning

g. Additional white water storage upsets and pulper dilution

Survey Questions (continued)

h. Recycle press effluent

i. Reuse of vacuum pump water

j. Broke storage

k. Wet lap machine

l. Separate cooling water

m. Cleaner reject to landfill

8. Steam Plant and Utility Areas

a. Segregated cooling water

b. Boiler blowdown and backwash waters utilization

9. Recycle of Effluent

a. Filtrate

b. Sludge

10. Stock Storage Consistencies: ________Unbleached________Bleached

Any limitations on fresh water availability

Any limitations on effluent discharge volume

Discuss process changes planned specifically with the water system

11. Primary motivation(s)* for water reduction systems
    (1) Currently in use

    (2) Under consideration in near future

*Possible motivations
- o limited freshwater supply or high cost
- o effluent limitations
- o product, chemical and energy recovery

Priority given to programs to further reduce water usage.

POTENTIAL PROBLEMS ENCOUNTERED IN WATER REUSE IN PAPER AND BOARD MANUFACTURE

Dissolved Solids Buildup	Suspended Solids Buildup	Thermal Energy Buildup
Slime	Dirt	Temperature
Foam	Erosion	Sizing Problems
Pitch	Fines	Machine Room Temperature Conditions
Corrosion	Felt Plugging	
Sizing	Wire Plugging	Reduced Vacuum Pulp Capacity
Color	Felt Life	
pH Control	Reduced Drainage Rate	
Precipitation	Shoer Plugging	
Scale		
Odor		

Major Problems with Reuse

COMMENTS:

A-3054

Report Number: RU-84/1
Contract Number: 14-34-001-1468 March 1984

FINAL TECHNICAL REPORT

For Contract Period September 1, 1981, through September 30, 1982

AN ASSESSMENT OF THE POTENTIAL FOR WATER REUSE IN THE PULP AND PAPER INDUSTRY

Submitted to:

U.S. Department of the Interior
Bureau of Reclamation
18th and C Streets, N.W.
Washington, D.C. 20240

Authors:

J. Craig Wyvill, Project Director
John C. Adams
G. Edward Valentine, Jr.
Thomas C. Shelnutt

Engineering Experiment Station
Georgia Institute of Technology
Atlanta, Georgia 30332

in cooperation with

Environmental Resources Center
Georgia Institute of Technology
Atlanta, Georgia 30332

ACKNOWLEDGEMENTS

The work upon which this report is based was supported in part by funds provided by the United States Department of the Interior, Office of Water Research and Technology, as authorized under the Water Research and Development Act of 1978. The Office of Water Research and Technology has since been terminated effective August 25, 1982, by Secretarial Order 3084 and its programs transferred to other bureaus and offices in the Department of the Interior. The Water Reuse Research and Development Program was among those transferred to the Bureau of Reclamation.

The authors would like to express their appreciation to everyone who provided assistance to this study effort. In particular, we would like to thank Robert Madancy of the U.S. Department of the Interior for his able direction and guidance. Further, we would like to thank each of the 25 mills who participated in our survey. Their contribution was invaluable in providing information about current practices and attitudes regarding water recycle and reuse. Finally, we would like to thank Dr. Lou Edwards of the University of Idaho for providing the use of his GEMS computer model together with his assistance in its operation.

DISCLAIMER

This report has been reviewed by the Office of Water Research of the Bureau of Reclamation, U.S. Department of the Interior, and approved for public dissemination. Approval does not signify that the contents necessarily reflect the views and policies of the Department of the Interior, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

ABSTRACT

This research study assesses the current extent of water reuse and recycle in the U.S. pulp and paper industry and identifies the potential for increasing overall water reuse and recycle. The study focuses on the 10 largest water consuming groups in the industry, found to utilize nearly 85% of the total water withdrawn by the entire industry. Using a systems analysis approach, major subprocess functions are identified and reviewed for technical limitations to further recycle and reuse. Regional, environmental, and economic constraints are also identified and projections made of the feasible water savings potential for the production groups studied. The study closes with an identification of areas where further research is needed to encourage water reuse and recycle.

Key words: *Water Recycle, *Pulp and Paper Industry, Water Reuse, Water Consumption Survey

CONTENTS

Acknowledgements ii
Disclaimer. iii
Abstract. iv
List of Figures viii
List of Tables xiii
Executive Summary xv

I. INTRODUCTION 1

II. OVERVIEW OF THE INDUSTRY 3
Introduction 3
Pulp and Paper Categorization 10
Pulp and Paper Mill Distribution 16
References - Section II 27

III. IDENTIFICATION OF PRODUCTION PROCESS SYSTEMS AND A PROCESS COMPUTER MODEL 28
Introduction 28
Process Subsystem Identification 28
Wood Preparation 29
Pulping 29
Pulp Washing 40
Pulp Screening 40
Bleaching 40
Cleaning and Refining 40
Paper Formation 45
Pressing 51
Drying 51
Finishing 55
Liquor Evaporation 55
Causticizing 55
Chlorine Dioxide Production 55
Power Generation and Cooling 59
Water Treatment 60
Process System Identification. 62
Dissolving Kraft 62
Market Bleached Kraft. 62
BCT (Board, Course, and Tissue) Bleached Kraft 62
Alkaline Fine 67
Unbleached Kraft 67
Unbleached Kraft and Semi-Chemical 67
Dissolving Sulfite Pulp. 67
Papergrade Sulfite 74
Integrated Miscellaneous Mills 74
Nonintegrated Fine Papers 74
Process Computer Modeling. 74
Model Selection 74
Strengths 79

Weaknesses 81
Model Adjustments 82
References - Section III 85

IV. EVALUATION OF CURRENT EFFORTS TO RECYCLE/REUSE WATER . . . 86
Introduction 86
Overview of Current Water Usage Patterns 86
Water Recycle/Reuse Constraints 105
Regional Constraints. 105
Environmental Constraints 106
Technical Constraints 107
Paper/Pulp Machine .107
Shower Plugging 107
Corrosion 109
Deposits 109
Biological Growth. .110
Paper Color. 110
Machine Clothing 111
Salts and Chemical Treatments. 112
Seal Water 112
Bleach Plant 112
Pulping, Washing, and Screening 116
Powerhouse 117
Economic Constraints 118
Mills Visited with Exceptionally Low Water Use 119
References - Section IV 122

V. THE FEASIBLE EXTENT OF WATER RECYCLE IN EXISTING MILLS . .126
Introduction 126
Pulp/Paper Machine .127
Bleach Plant 129
Digesting, Washing, and Screening 133
Causticizing 134
Powerhouse and Liquor Recovery 134
Pump Seal Water. 135
Intermittent Losses. 137
Computer Simulation of Selected Recycle Options. 137
Water Quality Constraints. 137
Dissolved Solids Concentration 138
Suspended Solids Concentration 139
Thermal Buildup 139
Computer Simulation Options. 140
Option 1 141
Option 2 142
Option 3 143
Option 4 144
Cases Considered 146
Assumptions. 146
Individual Options .147
Case 1 147
Case 2 149
Case 3 152
Case 4 155

Summary of Cases 1, 2, 3, and 4 155
Combinations of Options. .158
Case 5 158
Case 6 158
Case 7 162
Cases 8, 9, and 10 .162
References - Section V .170

VI. PROJECTED WATER DEMANDS IN THE PULP AND PAPER INDUSTRY . . .173
References - Section VI. .178

VII. CONCLUSIONS AND RECOMMENDATIONS 179
References - Section VII .182

Appendix

A GLOSSARY 183

B LEGEND OF ABBREVIATIONS .197

C AN OVERVIEW OF THE GEMS COMPUTER SIMULATION PROGRAM. 198

D MILL VISITS 213

LIST OF FIGURES

Figure	Title
II-1	Fresh Water Withdrawals by Paper & Allied Products Industries 4
II-2	Fresh Water Withdrawals by Major Industries 4
II-3	Use of Fresh Water Intake by Major Industries 5
II-4	Process Water Intake by Major Industries 8
II-5	Consumer Price Index: Water and Sewage Costs 9
II-6	Water Usage by the Three Major Segments of the Pulp & Paper Industry 12
II-7	Water Resources Council Regions 17
II-8	Regions Where the Pulp and Paper Industry Is Using the Greatest Volumes of Water. 25
II-9	Major U.S. Pulpwood Forests 26
II-10	Annual Precipitation 26
III-1	Typical Outdoor Wood Preparation Activity 31
III-2	Wood Grinding Technologies 33
III-3	Mechanical Pulp from Chips 34
III-4	Typical Chemimechanical Pulping Operation 35
III-5	Typical Kraft Pulping Process 36
III-6	Typical Calcium Base Sulfite Pulping Process. 37
III-7	Typical Semi-Chemical Pulping 38
III-8	Kamyr Continuous Kraft Digestor 39
III-9	Brown Stock Drum Washer System. 41
III-10	Types of Screening Technology 42
III-11	Typical Bleaching Process with Conventional Recycle Flows Highlighted 43

III-12 Cutaway View of a Quatropulper 44

III-13 Cutaway View of a Conical Refiner 46

III-14 Schematic of a Fourdrinier Paper Machine. 47

III-15 Schematic of a Cylinder Paper Machine 48

III-16 The Rotoformer 49

III-17 The Inverformer 49

III-18 Typical Shower Placement on a Fourdrinier 50

III-19 Disc Saveall Operating Sequence 50

III-20 Typical White Water Recovery System 52

III-21 Typical Pressing Techniques 53

III-22 Yankee Pressing Machine 54

III-23 Typical Dryer Section on Paper Machine. 54

III-24 Common Roll Coating Techniques 56

III-25 Black Liquor Recovery Furnace 57

III-26 Typical Causticizing Operation. 58

III-27 Mechanical Clarifier Design 60

III-28 Conventional Activated Sludge Facility. 61

III-29 Process Flow Diagram for Dissolving Bleached Kraft . .63

III-30 Process Flow Diagram for Market Bleached Kraft 65

III-31 Process Flow Diagram for BCT Bleached Kraft 66

III-32 Process Flow Diagram for Alkaline Fine 69

III-33 Process Flow Diagram for Unbleached Kraft 70

III-34 Process Flow Diagram for Unbleached Kraft and Semi-Chemical 72

III-35 Process Flow Diagram for Dissolving Sulfite Pulp. . . .73

III-36 Process Flow Diagram for Papergrade Sulfite 76

III-37 Process Flow Diagram for Nonintegrated Fine Papers. . .78

III-38 GEMS Process Blocks with Corresponding Production Process Activities 80

IV-1 Typical Kraft 5 Effect Black Liquor Evaporator Arrangement 90

IV-2 Typical Alkaline Brownstock Washing Process for Batch Digestion 92

IV-3 Typical Bleached Kraft Pulping Process. 93

IV-4 Typical Unbleached Kraft Pulping Process. 95

IV-5 Typical Calcium Base Sulfite Pulping Process. 97

IV-6 Typical Nonintegrated Fine Paper Process 99

IV-7 Typical Bleaching Process with Conventional Recycle Flows Highlighted 102

IV-8 High Level Water Recycle Schemes for Bleaching. . . . 103

IV-9 Typical Fourdrinier-Type Paper/Pulp Machine 104

IV-10 Typical Fourdrinier-Type Paper Machine Showing a High Level of Recycle 108

IV-11 Direct Countercurrent Bleaching Process with High Density First Stage for Minimum Fresh Water Requirements 114

V-1 Flowsheet of the Closed-Cycle Bleached Kraft Pulp Mill. 130

V-2 Comparison of Directly vs. Indirectly Heated Digesters 136

V-3 Dissolved Solids Behavior at the Headbox at Reduced Volume into the Felt Showers, Option 1 148

V-4 Suspended Solids Behavior at the Headbox at Reduced Volume into the Felt Showers, Option 1 148

V-5 Steam Consumption for Proper Wire Temperature at Reduced Volume into the Felt Showers, Option 1 150

V-6 Dissolved Solids Behavior at the Headbox with Recycle into the Gland Seals, Option 2. 151

V-7 Suspended Solids Behavior at the Headbox with Recycle into the Gland Seals, Option 2. 151

V-8 Steam Consumption for Proper Wire Temperature with Recycle into the Gland Seals, Option 2. 153

V-9 Dissolved Solids Behavior at the Headbox with Recycle into the Vacuum Pumps, Option 3. 153

V-10 Suspended Solids Behavior at the Headbox with Recycle into the Vacuum Pumps, Option 3. 154

V-11 Steam Consumption for Proper Wire Temperature with Recycle into the Vacuum Pumps, Option 3. 154

V-12 Dissolved Solids Behavior at the Headbox with Recycle into the Brownstock Washers, Option 4 156

V-13 Suspended Solids Behavior at the Headbox with Recycle into the Brownstock Washers, Option 4 156

V-14 Steam Consumption for the Proper Wire Temperature with Recycle into the Brownstock Washers, Option 4 157

V-15 Dissolved Solids Behavior at the Headbox, Options 1 & 2 159

V-16 Suspended Solids Behavior at the Headbox, Options 1 & 2 159

V-17 Steam Consumption for Proper Wire Temperature, Options 1 & 2 160

V-18 Dissolved Solids Behavior at the Headbox, Options 1 & 3 160

V-19 Suspended Solids Behavior at the Headbox, Options 1 & 3 161

V-20 Steam Consumption for Proper Wire Temperature, Options 1 & 3 161

V-21 Dissolved Solids Behavior at the Headbox, Options 2 & 3 163

V-22 Suspended Solids Behavior at the Headbox Options 2 & 3 163

V-23 Steam Consumption for the Proper Wire Temperature, Options 2 & 3 164

V-24	Dissolved Solids Behavior at the Headbox, Option 1 at 50% Recycle to Washers.	164
V-25	Suspended Solids Behavior at the Headbox, Option 1 at 50% Recycle to Washers.	165
V-26	Steam Consumption for Proper Wire Temperature, Option 1 at 50% Recycle to Washers.	165
V-27	Dissolved Solids Behavior at the Headbox, Option 2 at 50% Recycle at Washers.	166
V-28	Suspended Solids Behavior at the Headbox, Option 2 at 50% Recycle at Washers.	166
V-29	Steam Consumption for Proper Wire Temperature, Option 2 at 50% Recycle to Washer	167
V-30	Dissolved Solids Behavior at the Headbox, Option 3 at 50% Recycle to Washers.	167
V-31	Suspended Solids Behavior at the Headbox, Option 3 at 50% Recycle to Washers.	168
V-32	Steam Consumption for Proper Wire Temperature, Option 3 at 50% Recycle to Washers.	168
C-1	Schematic of Mixer Block	206
C-2	GEMS Schematic for Drum Washing	207
C-3	Sample Execution Input File	208
C-4	Sample Execution Output File	209
D-1	Distribution of Mills Surveyed by Water Resource Region	214

LIST OF TABLES

Table	Title
II-1	Manufacturing Water Use by Industry, 1975 7
II-2	Pulp and Paper Industry Subcategorization 11
II-3	Water Usage Statistics for Pulp and Paper Industry by Basic Subcategory 13
II-4	Ten Mill Subcategories Selected for Study 14
II-5	Regional Distribution and Water Requirements of the Ten Study Categories of the Pulp and Paper Industry 22
II-6	Regional Distribution of Pulp and Paper Mills and Water Requirements. 23
III-1	Pulp/Paper Production Subprocesses and Fresh Water Usage 30
III-2	Dissolving Bleached Kraft Statistics 64
III-3	Market Bleached Kraft Statistics. 64
III-4	BCT Bleached Kraft Statistics 68
III-5	Alkaline Fine Statistics 68
III-6	Unbleached Kraft Statistics 71
III-7	Unbleached Kraft and Semi-Chemical Statistics 71
III-8	Dissolving Sulfite Pulp Statistics. 75
III-9	Papergrade Sulfite Statistics 75
III-10	Integrated Miscellaneous Statistics 77
III-11	Nonintegrated Fine Paper Statistics 77
IV-1	Total Water Usage by Pulp and Paper Category. 87
IV-2	Comparison of Average Water Usage Versus the Lowest Water Users of the 10 Subcategories Studied. .88
IV-3	Market Bleached Kraft Water Recycling 94

IV-4	Unbleached Kraft Water Recycling.	96
IV-5	Papergrade Sulfite Water Reycling	98
IV-6	Nonintegrated Fine Paper Water Recycling.	100
V-1	Prime Energy Users in Integrated Pulp and Paper Mills	128
V-2	Potential Bleach Plant Recycle Schemes	131
VI-1	Growth of Industry (Production).	174
VI-2	Product Water Demand	175
VI-3	Total Water Usage.	176
D-1	Current Fresh Water Usage Rates of Mills Visited	216

EXECUTIVE SUMMARY

Fresh water usage by the pulp and paper industry has undergone a steady decline in the past three decades as conservation and recycle/reuse measures have been undertaken. The primary impetus to date for undertaking such measures has been to reduce energy consumption, to recover valuable waste products, and to comply with increasingly stringent environmental regulations. In recent years, however, an increasingly serious problem has begun to appear with growing regularity. Many regions of the country are experiencing limitations in high quality fresh water leading to an increased concern that continued industrial growth may have to be curtailed in selected areas. In light of these concerns, the Georgia Tech Engineering Experiment Station, under the sponsorship of the Department of the Interior, undertook a study to determine the status of water demand and recycle/reuse in the United States pulp and paper industry. The objective of this study was to determine what additional measures could be taken to further reduce fresh water demand and to assess the technical and economic constraints affecting widespread use of such techniques. This report summarizes the results of this study.

The study utilized a systems analysis approach to identify and evaluate water demand and recycle/reuse potentials. The first measures taken were designed to isolate the most water intensive production sectors of the industry. Following this identification, attention was focused on reviewing internal process and subprocess water flows in an effort to identify potential areas for further recycle/reuse. Ten broad production categories in the industry were found to utilize nearly 85% of the total fresh water intake for the industry. These categories were:

- o Dissolving Kraft
- o Market Bleached Kraft
- o Board, Coarse, and Tissue Bleached Kraft
- o Alkaline Fine
- o Unbleached Kraft
- o Unbleached Kraft and Semi-Chemical
- o Dissolving Sulfite Pulp
- o Papergrade Sulfite
- o Integrated Miscellaneous Mills
- o Nonintegrated Fine Papers

Working within these production groups, water demand was reviewed on a process/subprocess basis for each general subcategory. Where available, published statistical data was utilized and ultimately augmented with mill specific data collected from visits made to approximately 25 operating facilities across the country.

Each production subcategory was then reviewed with regard to the range and method of recycle/reuse currently in place. An array of different concepts were found to exist including such items as:

- o Whitewater recycle to showers and vacuum pump seals.
- o Recycle of a portion of the chlorination effluent back to the unbleached stock dilution.
- o Clean condensate recycling to washers.

Constraints to recycle/reuse were also studied to identify those circumstances limiting further action in this area. These constraints were found to fall into one of four general groups:

- o Regional
- o Environmental
- o Economic
- o Technical

After determining the extent to which pulp and paper manufacturers were recycling/reusing water and identifying those factors affecting these endeavors, the study then focused on methods of increasing recycle/reuse. Subprocesses in each production subcategory generally found to require freshwater were isolated as candidates for recycle/reuse consideration. These subprocesses were then reviewed with respect to the overall production process to determine if suitable sources of wastewater existed for use in each. An overall assessment of the water source and its use potential was also made.

In order to reduce the number of manual calculations made to verify the acceptability of a recycle/reuse option, a computer model was used. The program selected was a general pulp and paper process simulation known as "GEMS". This model allowed iterative evaluations of selected recycle/reuse options and provided point-to-point subprocess information with regard to flow and quality.

The study found several new or little used techniques for increasing water reuse/recycle. Among these were:

- o Enhanced white water recycle on the paper machine
- o White water recycle to the bleach plant.
- o More complete recycle of bleach plant effluent for stock dilution and washing.
- o Utilization of evaporator and blow gas condensate in liquor preparation.

Based on the historical performance of the industry in applying recycle/reuse technology and the economic incentives and constraints expected to exist in the future, a forecast was assembled to reflect the expected level of water demand by the major water using sectors of the industry by the year 2000. This forecast took into consideration the projected growth in production for the industry and the probable extent of increased water recycle/reuse that might take place. The forecasts show a total anticipated freshwater demand by the 10 subcategories studied of 3.8 billion gallons per day. This reflects an anticipated total freshwater withdrawal reduction of 53% (4.3 billion gallons per day) over the level that would have existed had no additional recycle/reuse measures been undertaken.

Section I

INTRODUCTION

Water recycle and reuse are terms with historical significance in the pulp and paper industry. Over the past thirty years, mills across the nation have taken giant strides in reducing their dependence on freshwater either through conservation measures or recycle/reuse. The industry currently is among the top major industrial groups in terms of the percentage of process water recycled prior to discharge. The primary impetus for much of the efforts undertaken to date can be traced to three motivating factors:

- o The recovery of valuable waste products
- o The reduction of costly energy usage
- o The avoidance of more costly measures needed to comply with increasingly stringent environmental regulations

In recent years, however, a new incentive has begun to appear with growing regularity in various regions across the country, namely a limitation on the availability of high quality freshwater. Such limitations are leading to community and industry concern that continued industrial growth in such areas may have to be curtailed.

It is within this setting that the study described herein was undertaken. The primary objective of the research effort was to characterize water usage patterns in the pulp and paper industry and to identify opportunities for increased water recycle/reuse. Implicit in this objective was the evaluation of regional and national recycle/reuse potentials, the identification of barriers to recycle/reuse, and an evaluation of areas where further research is needed to help overcome such barriers.

Throughout this report the words "recycle" and "reuse" appear. These terms have specific meanings with regard to this study. The term "recycle" refers to the practice of internally rechanneling a wastewater stream back to the process from where it originated or over to some auxiliary process in the mill without allowing the stream to exit the production area for processing at the waste treatment plant. The term "reuse" refers either to the use of wastewater that has been discharged from another mill or plant other than the one using it or the use of "treated" effluent from the operating mill's waste treatment plant.

Within the course of this study, it became apparent that there were differences between the motivation to recycle and the motivation to reuse water. As it relates to the pulp and paper industry, recycle has been the primary activity undertaken to date. Recycling allows the ready recovery of energy, chemicals, and fibers present in most waste streams. This recovery provides economic incentive for the undertaking of projects. Reuse on the other hand is more readily practicable by mills located in areas where water is extremely limited. Reuse allows a mill to obtain a sufficient quantity of process water to operate. This is true whether the water being used is from the mill's own treatment facility or from the treatment facilities of others nearby.

These distinct differences in motivation offer considerable insight into the future potential for water recycling and reuse. As water shortages begin to grow with more and more regularity, mills in affected areas can be expected to take actions designed to prevent production cutbacks including the reuse of wastewater streams that are deemed more reliable than the existing freshwater supplies. These measures can almost be considered drastic in that the effect of not undertaking them is to risk costly unscheduled production curtailments. Predictions of the potential for such action are difficult if not impossible to make at this time.

Recycle, on the other hand, seems destined to be pursued as it has in the past based on cost savings. The potential for the continued expansion of recycle efforts is more readily predictable based on projected changes in the net cost of energy, chemicals, and fibers. And even with recent delays in the enforcement of more stringent environmental standards, pressure will remain on mills across the nation to prevent further degradation of streams and rivers while increasing production volumes. This pressure will force mills to continue seeking recycle measures which avoid more costly treatment options. As a result, it appears that recycle will remain a more active technique than reuse through the year 2000.

Section II

OVERVIEW OF INDUSTRY

INTRODUCTION

The United States leads the world in the production of paper and paperboard products and can be expected to maintain its dominant role in world production for years to come. The pulp and paper industry in the United States is a diverse industry with a unique group of pressures forcing it toward a common understanding of problems. This section discusses the make-up of the industry and the diversity of resource availability to it as a function of geographical location. It also presents a comparison of this industry to other major industrial categories in terms of water demand, usage, and reuse.

More than 700 facilities in the nation are currently involved in the manufacture of pulp, paper, and paperboard products, representing Standard Industrial Classification (SIC) subgroups 2611, 2621, and 2631, respectively. These three subcategories of SIC 26 (Paper & Allied Products) are of primary interest to this study because together they account for 96% of the industry's total freshwater withdrawal (the volume of water taken into a manufacturing plant from an outside source). The fractional breakdown of water withdrawals for the industry is shown in Figure II-1.

The manufacture of pulp and paper involves the use of water at almost every subprocess; therefore, the industry depends on a readily-available, large supply of water. Integrated mills are typically located along major water bodies and utilize water for processing, generating power, transporting raw materials and products, and disposing of waste products.

The Paper & Allied Products sector ranks third in terms of freshwater withdrawals by manufacturing industries, accounting for 17% of all industrial withdrawal. As shown in Figure II-2, only Primary Metals (SIC 33) and Chemical & Allied Products (SIC 28) have greater water intakes than the paper industry.[1] By the year 2000, the paper industry is projected to be the largest manufacturing water user, both in terms of withdrawals and consumption*.[2] These factors make the pulp and paper industry a prime candidate for water reuse and recycle.

The ultimate use of freshwater intake by major industries is shown in Figure II-3.[1] Unlike other major water using industries which apply the majority of their water withdrawn to cooling purposes, the paper industry uses only 34% for cooling purposes and more than 60% in the manufacturing process itself. A comparison of the amount of

*Consumption is considered the difference between the volume of water that is withdrawn and that discharged. It is that water consumed in the production process; e.g., evaporated in cooling towers or sludge driers, or remaining in the product.

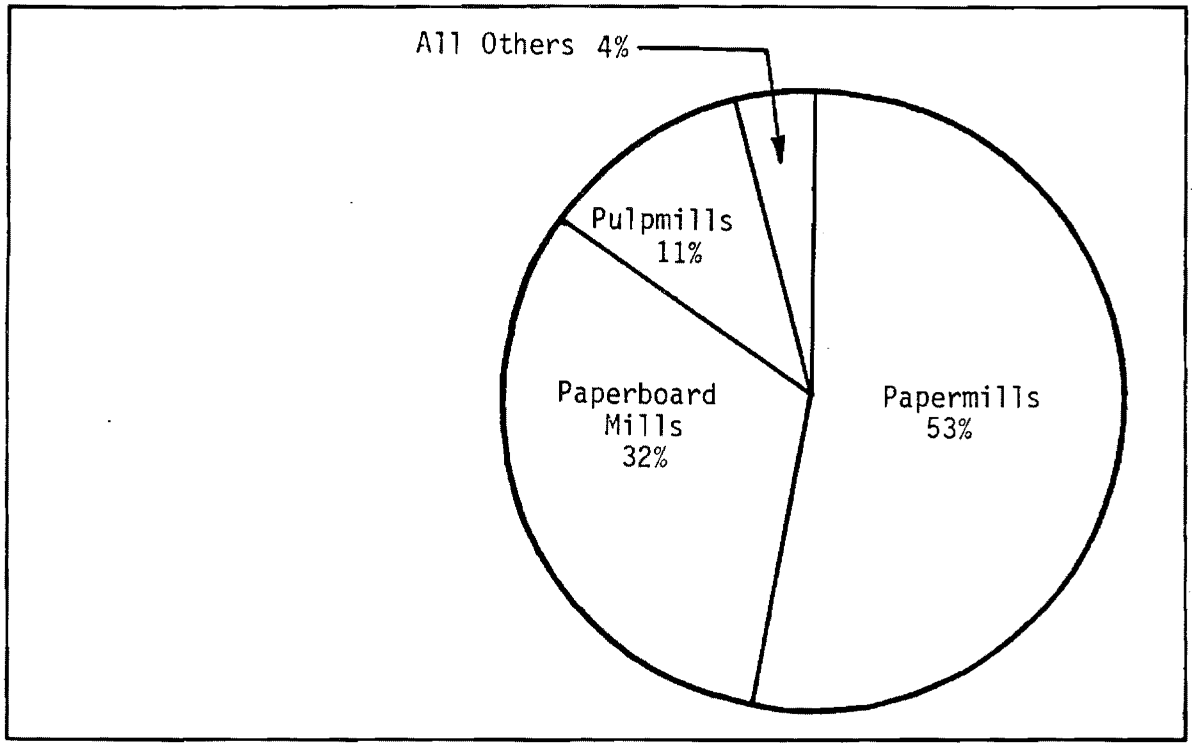


Figure II-1. FRESH WATER WITHDRAWALS BY PAPER & ALLIED PRODUCTS INDUSTRIES

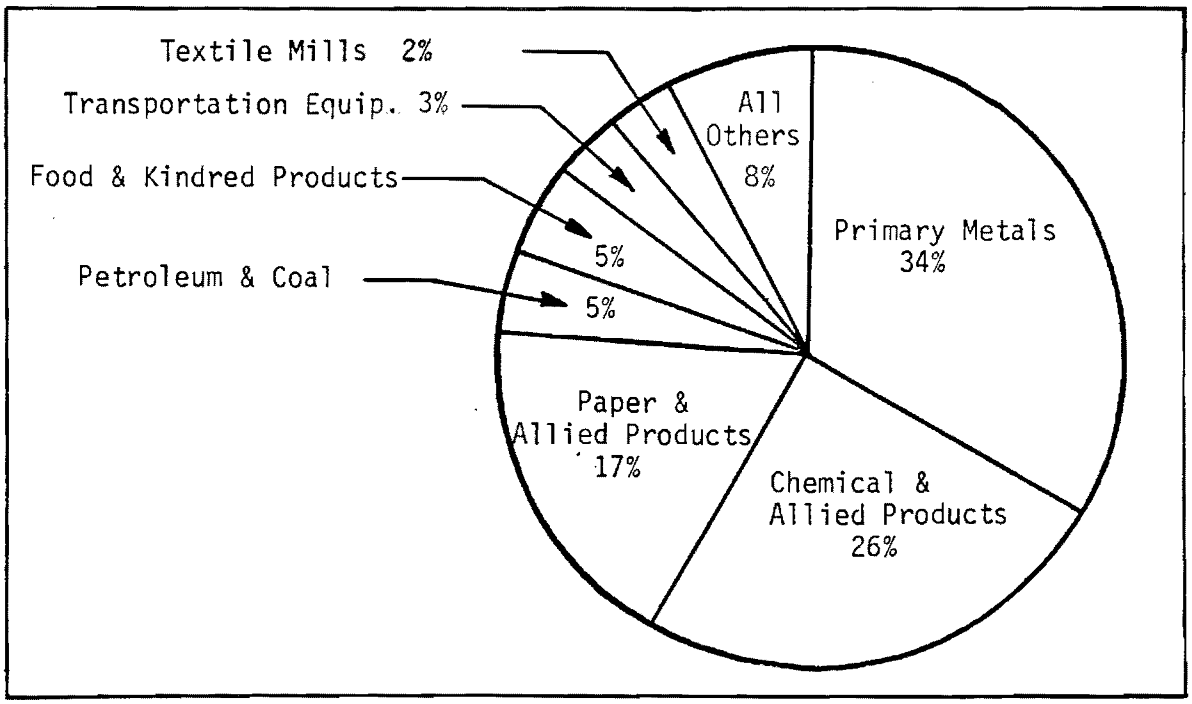


Figure II-2. FRESH WATER WITHDRAWALS BY MAJOR INDUSTRIES

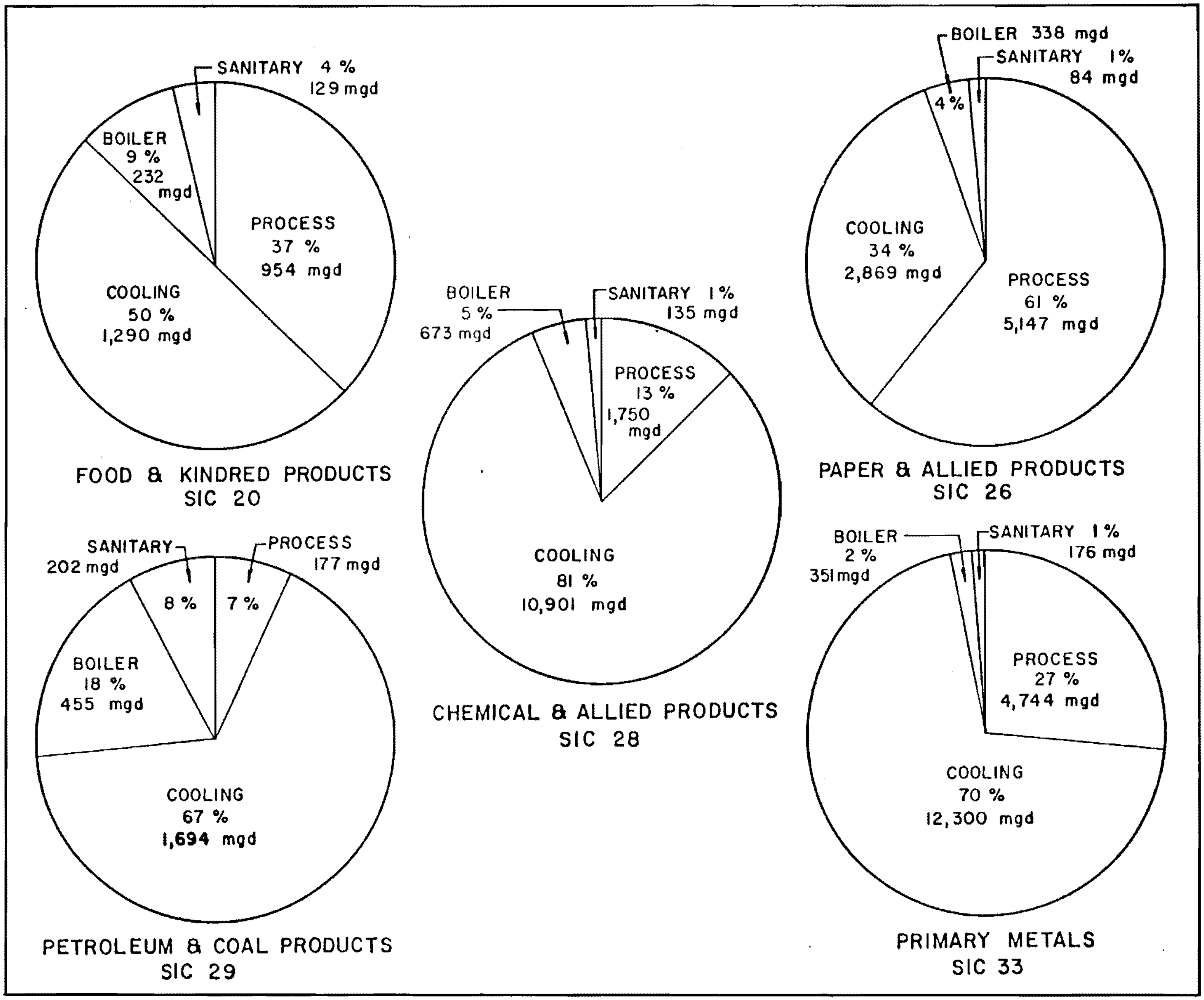


Figure II-3. USE OF FRESH WATER INTAKE BY MAJOR INDUSTRIES water used for processing for the major industries is shown graphically in Figure II-4. The paper industry is seen to be the single largest industrial process water user.

Withdrawals are strongly influenced by process parameters and production practices as well as internal and external factors that encourage recycling. There has been a long-term trend in the pulp and paper industry toward increased use of recycled water. The recycling of process water within pulp and paper mills is an attractive option for several reasons including:

- o Lower freshwater use and cost
- o Greater solids and chemical recovery
- o Greater heat recovery
- o Reduced effluent volume and cost
- o Completely within control of the mill

However, the mills frequently consider the cost of the water to be insignificant providing little motivation for efforts to reduce consumption. But, as shown in Figure II-5, if the cost of water supply and sewage continues to rise sharply as it did in the past decade, a genuine economic savings for water alone could be realized from conservation efforts.[2]

Measures to increase recycling often result in recovery of fiber, heat, and chemicals normally lost in the mill effluent. The value of their recovery helps to offset the high capital and operating costs typically required to implement recycle. In the past, the decision to utilize recovery/recycle techniques was simply made by weighing the capital and operating costs against the savings in chemicals and other raw materials. However, with the introduction of a third factor, environmental regulation, the decision now must account for additional savings in expensive wastewater treatment. The effluent limitations of the U.S. Environmental Protection Agency (EPA) regulations are such that end-of-pipe treatment, in many cases, cannot economically reduce pollutant discharges. More and more, it has become necessary to utilize internal recycling technologies as an alternative to the end-of-pipe treatment.

The pulp and paper industry has long recognized the potential benefits associated with water reuse. At the turn of the century when the paper machine was being developed, water use was approximately 150,000 gallons per ton. In the 1950's the water usage rate was down to 35,000 gallons per ton. Today, water usage for unbleached Kraft mills averages 15,000 gallons per ton with many mills using less than 10,000 gallons per ton. This effort has resulted in Paper & Allied Products producing the highest water recycle rate of all the industrial groups except for Petroleum & Coal Products.[2] The water usage and recycle rates for the various industrial groups are shown in Table II-1.

Table II-1. MANUFACTURING WATER USE BY INDUSTRY, 1975
(billion gallons per day)

Industry	Total Water Withdrawal	Recirculation Ratio	Gross Water Use
Chemicals & Allied Products	19.4	2.1	40.1
Primary Metals	18.9	1.5	28.2
Paper & Allied Products	8.9	2.9	26.1
Petroleum & Coal Products	4.7	5.0	23.7
Food & Kindred Products	2.9	1.6	4.5
Transportion Equipment	1.5	2.6	3.7
Textile Mill Products	0.6	2.8	1.7
All Other Manufacturing	4.8	1.8	8.6
National Average	61.7	2.2	136.6

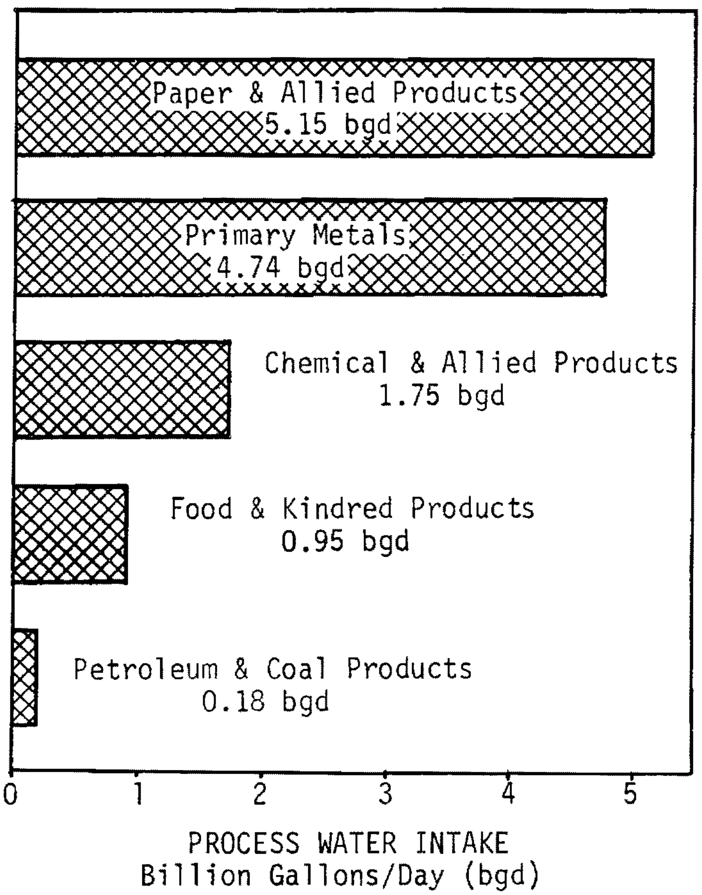


Figure II-4. PROCESS WATER INTAKE BY MAJOR INDUSTRIES

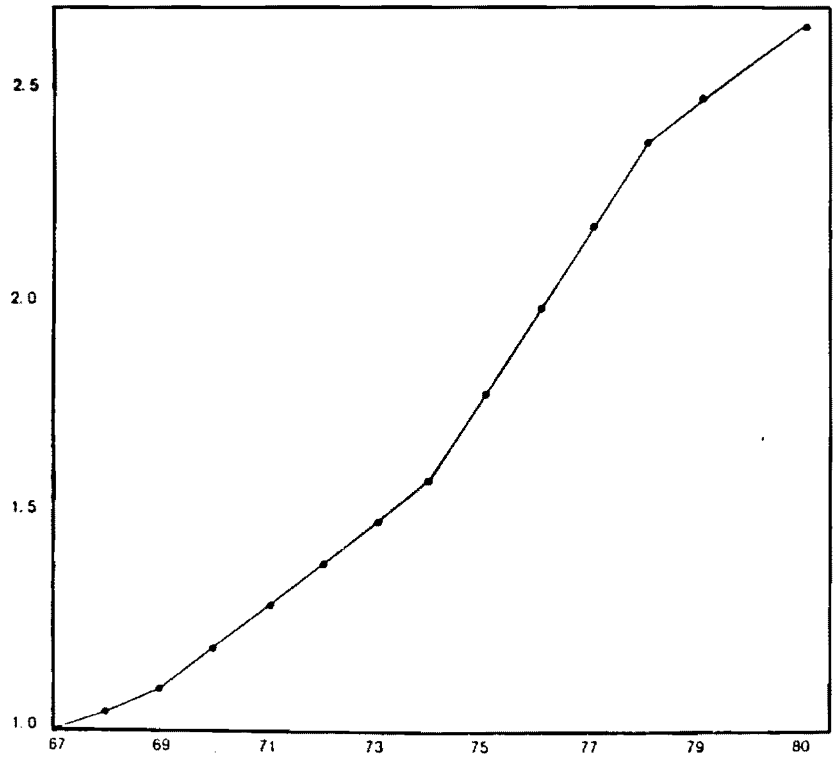


Figure II-5. CONSUMER PRICE INDEX:
WATER AND SEWAGE COSTS
(1967=1.00)

PULP AND PAPER CATEGORIZATION

Because of the variety and complexity of the pulp and paper industry, it became necessary to categorize it into functional subgroups having similar production processes that influence water usage. This breakdown aided in the evaluation of water requirements. In order to develop wastewater effluent limitations for the industry, the EPA has put together a subcategorization of the industry based on factors such as size and age of plant, raw material, processes employed, final products, water use, and waste constituents.[3] This subcategorization scheme, as shown in Table II-2, was adopted by the study team and has three major segments.

1. Integrated Mills -- Mills where pulp, paper or paperboard are manufactured on-site.
2. Secondary Fibers Mills -- Mills where wastepaper is used as the primary material to produce paper or paperboard.
3. Nonintegrated Mills -- Mills where paper or paperboard are manufactured but pulp is not manufactured on-site.

The comparison of the water usage by these segments is shown in Figure II-6. The integrated segment is the largest user of water at about 86% of the total, with the nonintegrated segment using 9% and the secondary fibers accounting for the remaining 5%.

A thorough statistical summary of the subcategories was compiled to allow for direct comparison based on number of mills and total estimated water requirements. This data is shown in Table II-3. From this data it was observed that less than 190 mills residing in ten categories provide nearly 72% of all production and account for 85% of the total water withdrawn. Based on these observations the study was focused on these ten subcategories alone to provide the opportunity for a more detailed assessment of water recycle/reuse potential. These ten subcategories are shown in Table II-4. It should be noted that nine out of the ten subcategories are integrated mills and the other is a nonintegrated mill. These subcategories are defined as follows:

Dissolving Kraft

This subcategory includes mills where a highly bleached pulp is produced using a "full cook" process employing a highly alkaline sodium hydroxide and sodium sulfide cooking liquor. Included in the manufacturing process is a "pre-cook" operation termed pre-hydrolysis. The principal product is a highly bleached and purified dissolving pulp used primarily for the manufacture of rayon and other products requiring the virtual absence of lignin and a very high alpha cellulose content.

Market Bleached Kraft

This subcategory includes mills where a bleached pulp is produced using a "full cook" process employing a highly alkaline sodium hydroxide and sodium sulfide cooking liquor. Unlike dissolving

Table II-2. PULP & PAPER INDUSTRY SUBCATEGORIZATION

Integrated Mills	Secondary Fiber Mills
Dissolving Kraft	Deink
Market Bleached Kraft	o Fine Papers
BCT Bleached Kraft	o Tissue Papers
Fine Bleached Kraft	o Newspaper
Soda	Tissue from Wastepaper
Unbleached Kraft	Paperboard from Wastepaper
o Linerboard	Wastepaper-Molded Products
o Bag and Other Mixed Products	Builders' Paper and Roofing Felt
Semi-Chemical	
Unbleached Kraft and Semi-Chemical	**Nonintegrated Mills**
Dissolving Sulfite Pulp	
o Nitration	Nonintegrated Fine Papers
o Viscose	Nonintegrated Tissue Paper
o Cellophane	Nonintegrated Filter and Nonwoven Papers
Papergrade Sulfite (Blow Pit Wash)	
Papergrade Sulfite (Drum Wash)	
Groundwood - Coarse, Molded, and News (C,M,N) Papers	
Groundwood - Fine Papers	
Groundwood-Chemi-Mechanical	

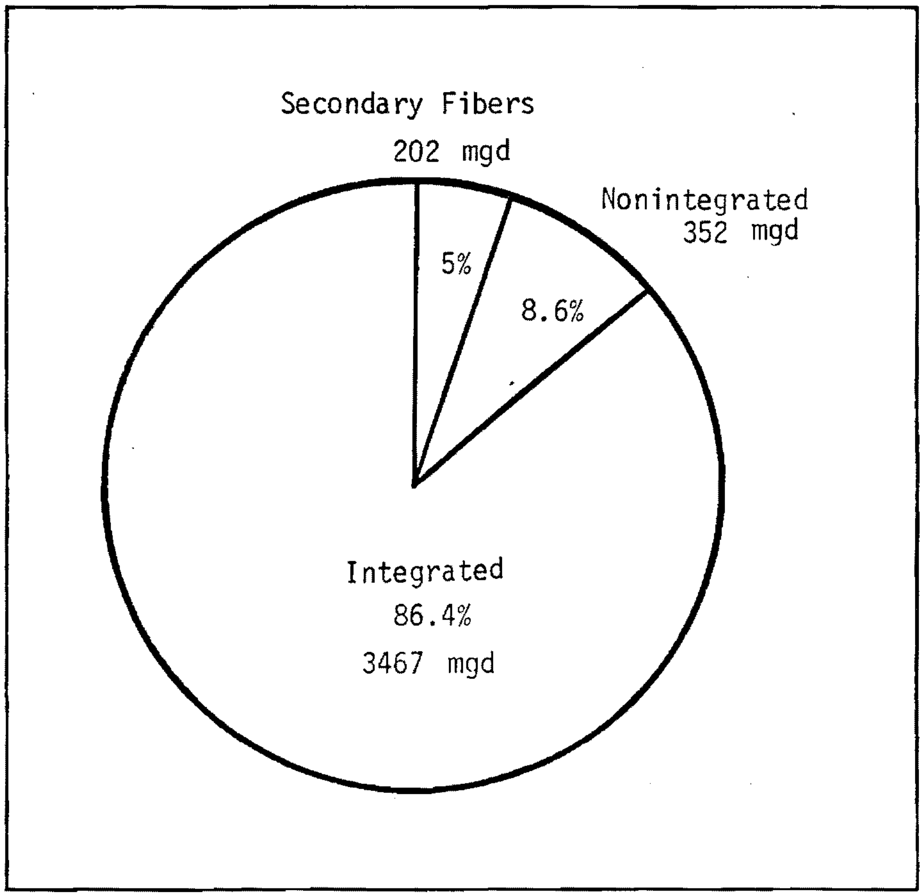


Figure II-6. WATER USAGE BY THE THREE MAJOR SEGMENTS OF THE PULP & PAPER INDUSTRY

TABLE II-3. WATER USAGE STATISTICS
FOR PULP AND PAPER INDUSTRY BY BASIC SUBCATEGORY

Mill Category	No. of Mills	Water Usage (c) Kgal/d	Rank Kgal/d
INTEGRATED			
Dissolving Kraft	3	159,125	10
Market Bleached Kraft	10	206,820	7
BCT Bleached Kraft[a]	8	250,848	5
Alkaline Fine	20	390,788	3
Unbleached Kraft	29	449,929	2
Dissolving Sulfite Pulp	6	211,118	6
Papergrade Sulfite	17	260,678	4
Groundwood-Thermo-Mechanical	3	13,496	22
Groundwood - Fine Papers	6	50,582	16
Integrated Miscell-aneous Mills	88	1,490,720	1
SECONDARY FIBERS			
Deinking Fine Paper	5	24,265	20
Newsprint[b]	3	N/A	N/A
Tissue from Wastepaper			
Industrial Tissue	9	2,953	25
Sanitary Tissue	12	6,480	26
SECONDARY FIBERS (con't)			
Paper from Wastepaper	146	84,621	11
Wastepaper - Molded Products	15	10,824	23
Builders' Paper and Roofing Felt	57	10,032	24
Secondary Fibers -	17	36,660	17
NON-INTEGRATED			
Fine Papers	41	170,494	9
Tissue Papers	26	67,361	12
Lightweight Papers	17	51,177	15
Filter and Nonwoven Papers	14	2,229	28
Paperboard	12	14,746	21
Miscellaneous	34	36,278	18
	Total	4,162,766	

(a) paperboard builders paper
(b) production data confidential
(c) average for mills report x calculated tons per day

Table II-4. TEN MILL SUBCATEGORIES SELECTED FOR STUDY

INTEGRATED MILLS	CODE
Dissolving Kraft	Ia
Market Bleached Kraft	Ib
BCT Bleached Kraft	Ic
Alkaline Fine	Id
Unbleached Kraft	Ie
Unbleached Kraft & Semi-Chemical	Ig
Dissolving Sulfite Pulp	Ih
Papergrade Sulfite	Ii
Integrated Miscellaneous	Ik
NONINTEGRATED MILLS	
Nonontegrated Fine Paper	IIa

Kraft, quality constraints are not nearly as stringent for this subcategory. Papergrade market pulp is produced at mills representative of this subcategory.

BCT (Board, Coarse, and Tissue) Bleached Kraft

This subcategory includes the integrated production of bleached Kraft pulp and board, coarse, and tissue papers. Bleached Kraft pulp is produced on-site using a "full cook" process employing a highly alkaline sodium hydroxide and sodium sulfide cooking liquor. The principal products include paperboard (B), coarse papers (C), tissue papers (T), and market pulp.

Alkaline Fine

This subcategory includes the integrated production of bleached Kraft pulp and fine papers. Bleached Kraft pulp is produced on-site using a "full cook" process employing a highly alkaline sodium hydroxide and sodium sulfide cooking liquor. Also included are mills producing bleached soda pulp on-site using a "full-cook" process employing a highly alkaline sodium hydroxide cooking liquor. The principal products are fine papers (which include business, writing, and printing papers) and market pulp.

Unbleached Kraft

This subcategory includes mills where pulp is produced without bleaching using a "full cook" process employing a highly alkaline sodium hydroxide and sodium sulfide cooking liquor. The pulp is used on-site to produce linerboard, the smooth facing in corrugated boxes, and bag papers.

Unbleached Kraft and Semi-Chemical

This subcategory includes mills where pulp is produced without bleaching using two pulping processes: unbleached Kraft and semi-chemical. Spent semi-chemical cooking liquor is burned within the Kraft chemical recovery system. The pulps are used on-site to produce both linerboard and corrugating medium used in the production of corrugated boxes.

Dissolving Sulfite Pulp

This subcategory includes mills where a highly bleached and purified pulp is produced from softwoods using a "full cook" process employing strong solutions of sulfites of calcium, magnesium, ammonia, or sodium. The pulps produced by this process are viscose, nitration, cellophane, or acetate grades and are used principally for the manufacture of rayon and other products that require the virtual absence of lignin.

Papergrade Sulfite

This subcategory includes integrated production of sulfite pulp and paper. Unlike dissolving sulfite pulp, quality constraints are not nearly as stringent for this subcategory. The sulfite pulp is produced on-site using a "full cook" process employing an acidic cooking liquor of sulfites of calcium, magnesium, ammonia, or sodium. Following the cooking operations, the spent cooking liquor is washed from the pulp in blow pits, vacuum or pressure drums. Also included are mills using belt extraction systems for pulp washing. The principal products include tissue papers, newsprint, fine papers, and market pulp.

Integrated Miscellaneous Mills

This subcategory includes mills that use multiple pulping operations or miscellaneous pulping processes not adequately described by other integrated subcategory definitions.

Nonintegrated Fine Papers

This subcategory includes nonintegrated mills where fine papers are produced from purchased pulp. The principal products of this process are printing, writing, business, and technical papers.

PULP AND PAPER MILL DISTRIBUTION

Identifying where mills are located and what water resources are available in those locations was pursued as a means of determining where strong motivations to recycle/reuse water exist in the pulp and paper industry. The nation has been divided into 21 major water regions for compiling and analyzing water resources data and further subdivided into 106 subregions by the U.S. Water Resources Council. The 21 major water resources regions shown in Figure II-7, are hydrologic areas that have either the drainage area of a major river or combined drainage areas of a series of rivers. A wealth of data on water supply, water needs and availability, and wastewater discharges has been published in "The Nation's Water Resources, The Second National Assessment."[4] This report identifies problems such as inadequate surface-water supply, overdraft of groundwater, pollution of surface water, and pollution of groundwater for the regions. All three factors are important in the context of this study and, therefore, these water resource regions were used as a geographic means of grouping pulp and paper mills. A brief description of the regions including the major river systems and total area is presented below.

New England Region (1)

The New England Region has over 44 million acres, slightly over 2% of the total area of the contiguous United States. The region's abundant water resources, 30,000 miles of streams, more than 5,000 lakes, and 6,000 miles of coastline, include New England's largest single basin, that of the Connecticut River. Most of the New

Figure II-7. WATER RESOURCES COUNCIL REGIONS

England Region rivers flow in a generally southerly or southeasterly direction toward Long Island Sound or the Atlantic Ocean. Exceptions are the Saint John River and the Lake Champlain and Lake Memphremagog drainages.

Mid-Atlantic Region (2)

The Mid-Atlantic Region covers over 66 million acres. Rivers in the northern half of the region flow generally southward to the ocean; the southern rivers flow in an easterly direction. The Hudson and the Delaware Rivers flow to the Atlantic Ocean directly; the Susquehanna, Potomac, Rappahannock, York, and James Rivers empty into the Chesapeake Bay. The harbors and waterways of the region are an integral part of the nation's transportation system.

South Atlantic-Gulf Region (3)

The South Atlantic-Gulf Region encompasses a total area of over 173 million acres. The region contains 24 major river basins including the Roanoke, the Cape Fear, the Savannah, the Suwannee, the Tombigbee, and the Pearl and many minor coastal river systems.

Great Lakes Region (4)

The Great Lakes Region, about 4% of the total area of the 48 contiguous United States, contains over 85 million acres. Waters from Lake Superior, Lake Michigan, and the Georgian Bay all drain into Lake Huron, which discharges water to Lake Erie through the St. Clair River, Lake St. Clair, and the Detroit River. Lake Erie, in turn, drains through the Niagara River to Lake Ontario, whose outlet is the head of the St. Lawrence River. Most of the water withdrawn from the Great Lakes hydrologic system comes directly from the lakes, which all together are the world's largest surface body of freshwater. An important navigation system is formed by the lakes and their connecting waterways and channels.

Ohio Region (5)

The Ohio Region embraces a total area of over 102 million acres. The Ohio River, the region's primary river, is formed by the confluence of the Allegheny and the Monongahela Rivers at Pittsburgh and is joined by major downstream tributaries. It flows in a southwesterly direction and joins the Mississippi River at Cairo, Illinois. The Ohio River is a key element of the nation's inland waterway system.

Tennessee Region (6)

The Tennessee Region covers an area of over 27 million acres. Seven large and numerous small rivers feed the Tennessee River as it makes its U-shaped course through the region. Parts of seven states are drained--more than half of Tennessee and smaller portions of Alabama, Georgia, Kentucky, Mississippi, North Carolina, and Virginia.

Upper Mississippi Region (7)

The Upper Mississippi Region includes the drainage area of the Mississippi River above its confluence with the Ohio River and encompasses over 115 million acres. Many rivers flow through the region in a general north-south direction, and the Mississippi River bisects the area. Tributaries of the Mississippi drain most of Minnesota, Wisconsin, Illinois, and Iowa; a significant portion of Missouri; and small areas in Indiana, Michigan, and South Dakota. The Upper Mississippi River is a key element in the nation's inland waterway system. Large amounts of groundwater are stored within much of the region.

Lower Mississippi Region (8)

The total area of the Lower Mississippi Region is over 67 million acres which include portions of Missouri, Tennessee, Kentucky, Arkansas, Mississippi, and Louisiana. The Mississippi River and the Gulf Intracoastal Waterway are nationally important navigation systems.

Souris-Red-Rainy Region (9)

The Souris-Red-Rainy Region encompasses about 35 million acres in the drainage areas of the three rivers. Flowing northward, the Souris-Red-Rainy Rivers eventually empty into Canada's Hudson Bay.

Missouri Region (10)

The Missouri Region contains one-sixth of the total area of the 48 contiguous United States, over 327 million acres. There are few natural lakes; most of the region's available water areas are found at manmade reservoirs. Six large reservoirs on the Missouri River mainstream generate most of the region's hydropower and provide flood protection and recreation water. They also maintain adequate flows for an 8-month navigation season and for water quality and water supply needs. These reservoirs divert water northeastward and eastward for irrigation as well as for municipal and industrial needs. Other tributary manmade reservoirs provide additional storage capacity and most of the water surface for water related recreation as well as for fish and wildlife propagation and preservation.

Arkansas-White-Red Region (11)

The Arkansas-White-Red Region has over 156 million acres. The three rivers drain all of Oklahoma and parts of Colorado, Kansas, Missouri, Arkansas, New Mexico, Texas, and Louisiana. The Arkansas and White Rivers discharge waters into the Mississippi River, and the Red River flows into the Atchafalaya River.

Texas-Gulf Region (12)

The Texas-Gulf Region includes a total of almost 114 million acres. Virtually all of the region lies within Texas, although small portions of Louisiana and New Mexico are included. Much of the region consists of the drainage areas of the Sabine, Neches, Trinity, San Jacinto, Brazos, Colorado, Lavaca, Guadalupe, San Antonio, and Nueces Rivers and their associated coastal basins. These rivers drain in a general northwest-southeast course to the Gulf of Mexico.

Rio Grande Region (13)

The Rio Grande Region, in the southwest corner of the United States, totals almost 88 million acres. The Rio Grande River flows south-southeasterly to the Gulf of Mexico; its waters are regulated by various treaties and compacts between the United States and Mexico and among Colorado, New Mexico, and Texas. Closed basins are important in the region's hydrology.

Upper Colorado Region (14)

The Upper Colorado Region contains almost 66 million acres in Arizona, Colorado, New Mexico, Utah, and Wyoming.[1] The Colorado River and its tributaries are the lifeblood of the region. The allocation and use of water in the region are governed by various interstate and international treaties and compacts. A number of reservoirs have been constructed to regulate the erratic streamflows; to provide water for irrigation, municipal, industrial, and other uses; and to meet compact commitments to the Lower Colorado Region.

Lower Colorado Region (15)

The Lower Colorado Region encompasses a total area of over 99 million acres. It includes several closed basins in Arizona, western New Mexico, southern Nevada, southwestern Utah, and some areas in Arizona and new Mexico that drain into Mexico. Except for a portion in southern California, the region is hydrologically defined by the drainage area of the Colorado River below Lee Ferry, Arizona. The Lower Colorado River Basin receives an annual apportionment of Colorado River water as established by the Colorado River Compact.

Great Basin Region (16)

The Great Basin Region encompasses about 89 million acres in Utah, Nevada, and Idaho. Most of the streamflow in the region originates in the high mountains at its eastern and western edges. The region is part of a hydrologically closed basin, so all of the rivers and streams eventually end in terminal lakes or sinks where evaporation creates high salinities.

Pacific Northwest Region (17)

The Pacific Northwest Region occupies over 173 million acres in the northwestern portion of the United States. The region's major rivers are the Columbia and the Snake. The Puget Sound area is a unique resource of great significance to the region.

California Region (18)

The California Region encompasses about 105 million acres with 1,050 miles of coastline. Two important, intensively developed rivers are the Sacramento and the San Joaquin which drain California's central valley and flow to the delta at San Francisco Bay. Other significant rivers in the northern coastal area, such as the Klamath and the Eel, are not as extensively utilized.

Alaska Region (19)

The Alaska Region accounts for one-sixth of the total area of the United States or over 375 million acres. Except for the Yukon and Porcupine, all major streams in the region originate in Alaska. The Alsek, Taku, and Stikine streams also have their headwaters in Canada. All of the rivers and streams flow into either the Artic Ocean, the Bering Sea, or the Pacific Ocean.

Hawaii Region (20)

The Hawaiian Archipelago contains 132 islands, shoals, and reefs, which equal about 4 million acres within the State of Hawaii. There are more than 200 perennial and temporary streams, but no large watersheds comparable to mainland stream systems.

Caribbean Region (21)

Puerto Rico, the larger of the two subregions of the Caribbean Region, has a territory of slightly more than 2 million acres. The U.S. Virgin Islands consist of a total area of about 85,000 acres. Most of the rivers in Puerto Rico are short in length, and none are very large in size or flow. The largest river, the Rio Grande de Loiza, has a drainage area of only 310 square miles. Streamflow in the Virgin Islands is ephemeral, and stream channels respond quickly to rainfall due to the extremely steep topography and tiny watershed areas.

The pulp and paper mills of interest of this study were found to be located in 15 of the 21 water regions. The number and types of mills along with freshwater withdrawals for the 10 study subcategories are tabulated by water resource region in Table II-5. The regions of greatest water use by the pulp and paper industry are the South Atlantic-Gulf, Pacific Northwest, Lower Mississippi, New England, Mid-Atlantic and Great Lakes. These regions use 36.7%, 19.1%, 11.3%, 6.7%, 5.9%, and 4.8% respectively of the total water use as summarized in Table II-6. In addition, these six regions, highlighted in Figure

Table II-5. Regional Distribution and Water Requirements of the Ten Study Catagories of the Pulp and Paper Industry

NEW ENGLAND (1)			MID ATLANTIC (2)			SOUTH-ATLANTIC (3)			GREAT LAKES (4)			OHIO (5)		
Cate-gory*	No. of Mills	Water Usage**	Cate-gory	No. of Mills	Water Usage**	Cate-gory	No. of Mills	Water Usage**	Cate-gory	No. of Mills	Water Usage**	Cate-gory	No. of Mills	Water Usage**
Ib	1	20	Id	3	80	Ia	2	110	Id	2	47	Ib	1	7
Ic	1	22	Ii	2	58	Ib	2	57	Ie	1	25	Id	2	51
Id	3	69	Ik	4	58	Ic	4	161	Ii	3	14	Ik	1	26
Ik	4	99	IIa	7	22	Id	2	70	Ik	3	45	IIa	6	8
IIa	12	40				Ie	16	243	IIa	12	49			
						Ig	3	73						
						Ik	18	677						
Total	21	250		16	218		47	1391		21	180		10	92

TENNESSEE (6)			UPPER MISSISSIPPI (7)			LOWER MISSISSIPPI (8)			SOURIS-RED RAINY (9)			ARKANSAS WHITE RED (11)		
Cate-gory*	No. of Mills	Water Usage**	Cate-gory	No. of Mills	Water Usage**	Cate-gory	No. of Mills	Water Usage**	Cate-gory	No. of Mills	Water Usage**	Cate-gory	No. of Mills	Water Usage**
Id	1	12	Id	1	15	Ia	1	38	Id	1	25	Ie	2	11
Ie	1	25	Ie	2	12	Ib	1	35				Ig	1	20
Ik	1	37	Ii	5	35	Ic	1	12				Ik	1	6
			Ik	1	13	Id	3	94						
			IIa	1	1	Ie	2	26						
						Ig	2	38						
						Ik	6	187						
Total	3	74		10	76		16	420		1	25		4	37

TEXAS GULF (12)			LOWER COLORADO (15)			PACIFIC-NORTHWEST (17)			CALIFORNIA (18)			ALASKA (19)		
Cate-gory*	No. of Mills	Water Usage**	Cate-gory	No. of Mills	Water Usage**	Cate-gory	No. of Mills	Water Usage**	Cate-gory	No. of Mills	Water Usage**	Cate-gory	No. of Mills	Water Usage**
Ic	2	82	Ik	1	12	Ib	1	30	Ib	1	22	Ih	1	45
Id	1	35				Ic	2	52	Id	1	12	Ik	1	42
Ie	1	10				Ie	3	44	Ik	1	12			
Ik	2	29				Ig	2	23	IIa	2	4			
						Ih	2	65						
						Ii	4	97						
						Ik	11	396						
						IIa	1	4						
Total	6	166		1	12		26	711		5	50		2	87

*Mill category codes identified in Table II-4.

**In mgd

Table II-6. REGIONAL DISTRIBUTION OF PULP AND PAPER MILLS AND WATER REQUIREMENTS

Region	No. of Mills	Water Usage(mgd)	Percent of Total Water
New England	21	250	6.7
Mid Atlantic	16	218	5.9
South-Atlantic	47	1,391	36.7
Great Lakes	21	180	4.8
Ohio	10	91	2.4
Tennessee	3	74	2.0
Upper Mississippi	10	76	2.0
Lower Mississippi	16	420	11.3
Souris-Red Rainy	1	25	0.7
Arkansas White-Red	4	37	1.0
Texas-Gulf	6	166	4.5
Lower Colorado	1	12	0.3
Pacific Northwest	26	711	19.1
Califorina	5	50	1.3
Alaska	2	47	1.3
Total	189	3,748	100.0%

II-8, collectively account for 84.5% of the daily water withdrawn by the paper manufacturing sector.

The main reason why pulp and paper mills are concentrated in the regions indicated above is because these areas have the major pulpwood forests. The Southern, Northern and West Coast Forests are shown in Figure II-9; together they supply about 90% of the U.S. pulpwood. These forests require an adequate supply of rainfall in order to prosper. Areas of the U.S. with 30 inches or more of rainfall annually are mapped in Figure II-10. Comparing Figures II-8, II-9 and II-10 shows the interrelationship between the pulp and paper industry, the pulpwood forests, and rainfall. The rainfall not only supplies water for the trees but also replenishes surface and groundwater supplies.

In general, mills are located in areas with an ample supply of water. However, periodic water shortages can occur as a result of drought, contamination, or other economic, social, and environmental causes. Competition for existing sources plus uncertainties of supply are incentive enough for many mills to try to reduce water use.

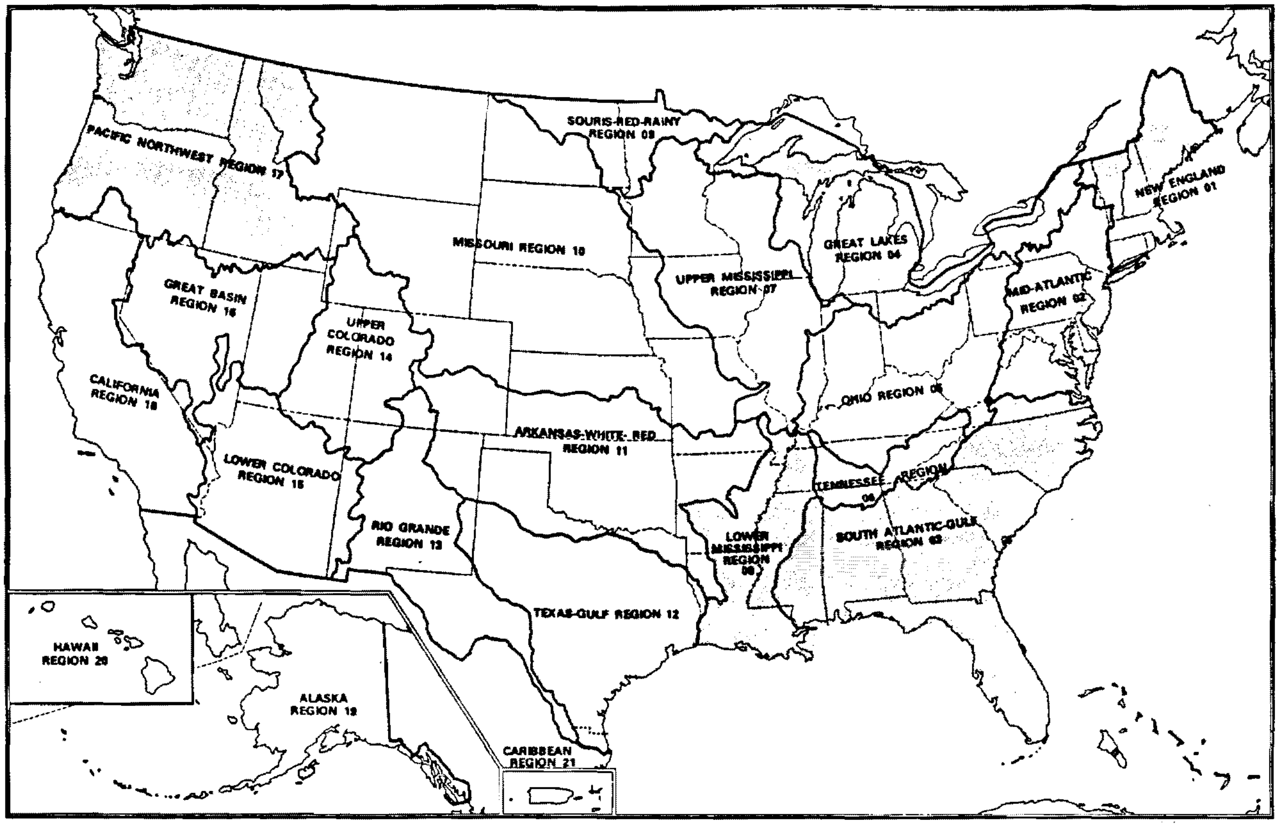


Figure II-8. REGIONS WHERE THE PULP & PAPER INDUSTRY IS USING THE GREATEST VOLUMES OF WATER (SHADED AREAS)

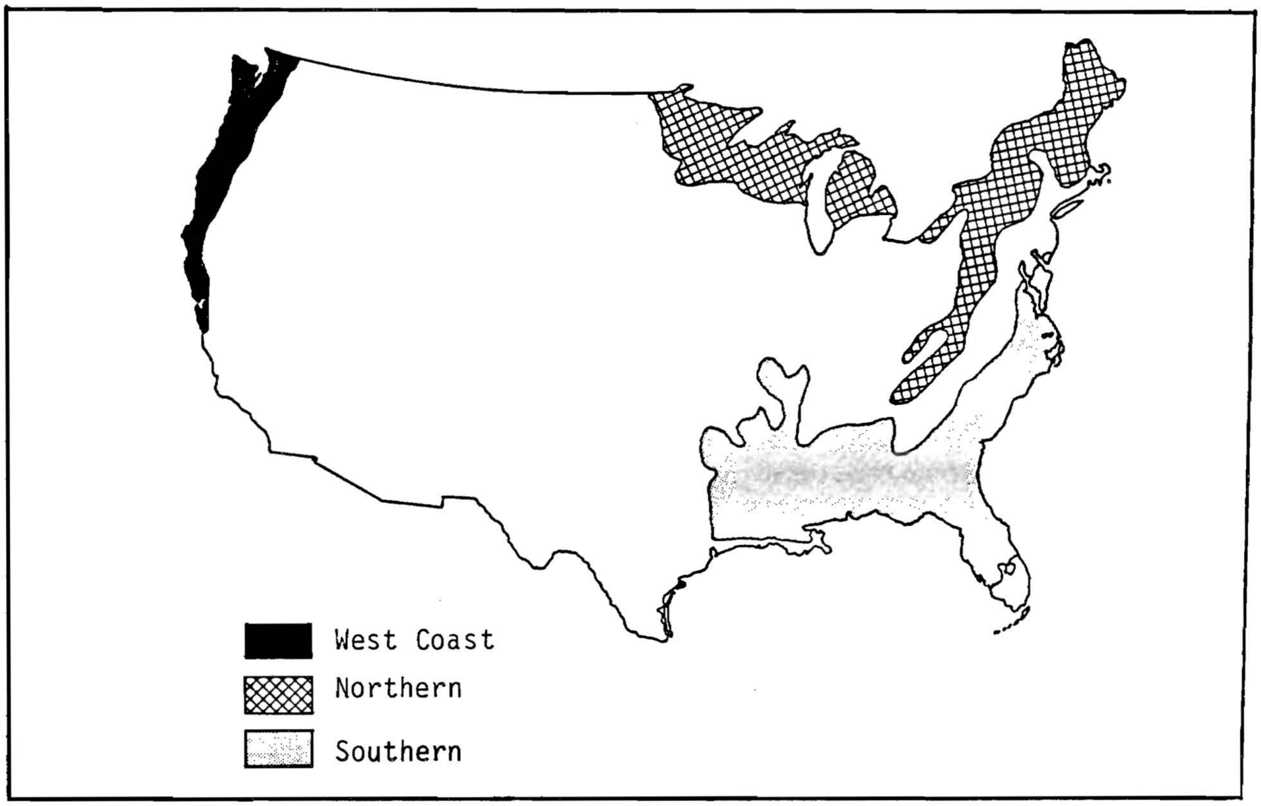


Figure II-9. MAJOR U.S. PULPWOOD FORESTS

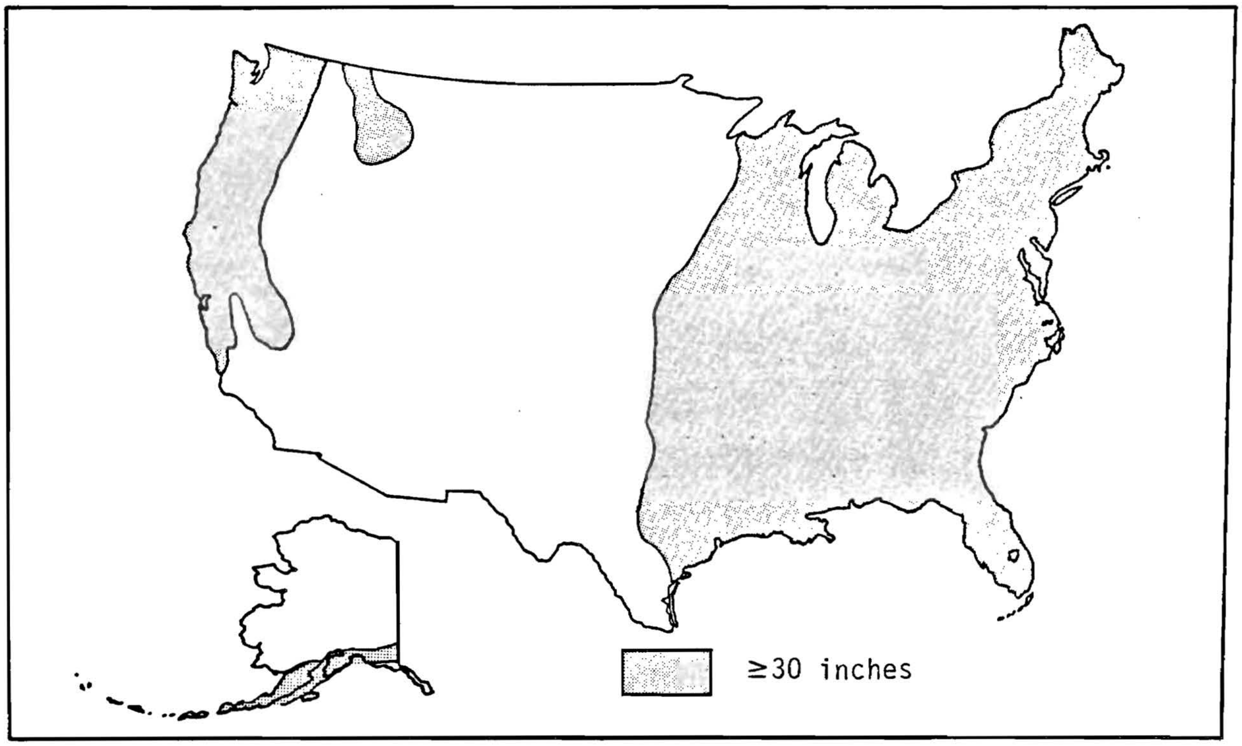


Figure II-10. ANNUAL PRECIPITATION

References - Section II

1. Department of the Interior - OWRT, "Water Reuse and Recycling - Volume 1," April 1979.

2. Yulke, S.G.; O'Rouke, J.T.; Asano, T.; "Water Reuse in the Pulp and Paper Industry in California," Proceedings of the Water Reuse Symposium II, August, 1981.

3. U.S. Environmental Protection Agency, "Development Document for Proposed Effluent Limitations Guidelines and Standards for the Pulp, Paper and Paperboard Mills Point Source Categories," U.S. Government Printing Office, Washington, D.C., 1981.

4. U.S. Water Resources Council, "The Nation's Water Resources, The Second National Water Assessment," December 1978.

Section III

IDENTIFICATION OF PRODUCTION PROCESS SYSTEMS AND A PROCESS COMPUTER MODEL

INTRODUCTION

To identify the potential for water reuse/recycle in the pulp and paper industry, a systems analysis approach was used. This analysis necessitated breaking each general production process into a series of discrete subprocesses which could be evaluated in terms of water demand, process quality constraints, and alternate methods for accomplishing that specific operation. However, by breaking the general processes into discrete parts, the number of calculations required to evaluate the impact of alternate options on production quality went up considerably. Therefore, at the outset of the study it was determined that a general computer simulation model capable of quickly calculating the effects of various reuse/recycle options would be necessary.

This section discusses the process "trains" developed for each production subcategory studied together with the identified water demands and constraints common to each subprocess in the "train". Further, there is a discussion of the efforts undertaken to select a computer model from among the several currently available today. An explanation of the manner in which the selected model was set up and the input parameters verified for accuracy and representativeness in the application areas under study is also included.

PROCESS SUBSYSTEM IDENTIFICATION

There are a number of subprocess groupings possible for describing how pulp and paper is produced. Perhaps the most common is by production department:

- Wood Preparation
- Pulping Plant
- Pulp Washing
- Bleaching
- Paper Plant
- Energy Systems
- Waste Treatment

However, these departments do not in themselves adequately define the production techniques used to produce pulp and paper products.

These departments were therefore further refined by the major functional activity performed in each area. Listed below are the common activities undertaken:

- o Wood Preparation
- o Pulping
- o Pulp Washing
- o Pulp Screening
- o Bleaching
- o Cleaning and Refining
- o Paper Formation
- o Pressing
- o Drying
- o Finishing
- o Liquor Evaporation
- o Causticizing
- o Chlorine Dioxide Production
- o Power Generation and Cooling
- o Waste Treatment

These functional activities were found to provide a satisfactory compromise between simplification (for study manageability) and detail (for accurate engineering evaluation). They were therefore selected to provide the basic blocks to be used in constructing process "trains" for each subcategory evaluation. Table III-1 shows typical freshwater requirements for the various subprocesses associated with the above functional activities. Below is a brief description of each functional activity together with an identification of the general types of water demand common to each and a description of known alternate technologies typically used to accomplish each function.

Wood Preparation[1]

In this activity, raw materials entering the mill are processed. Purchased wood chips are screened and conveyed to storage for use by the pulp mill. Logs are stored, debarked, cut to length (if necessary), and chipped (see Figure III-1).

Water use typically is small in the wood preparation process. Some mills use a water flume to convey logs from storage to the debarking area but most mills use mechanical conveyors. A number of sawing, grinding, cleaning, and sluicing functions occur in the wood preparation area in which water is used as a cooling or conveying medium. The volume of water demanded by a specific mill depends on the degree of mechanical technology employed. For example, hydraulic debarking machines using a high pressure water spray knife require high volumes of water. Mechanical debarking techniques on the other hand, such as drum debarkers or scraper-type debarkers, accomplish the same function without large water flows.

Pulping[2]

In this operation wood chips are converted into a soft fibrous mass (pulp) suitable for use in making paper or paperboard products. There are many variations of pulping techniques, each having its own unique advantage based on wood type or final product. Below is a brief discussion of five of the most common techniques in use today:

Table III-1. PULP/PAPER PRODUCTION SUBPROCESSES AND FRESH WATER USAGE

Production Subprocess	Range of Water Usage (gpt)	Purpose of Fresh Water Usage
Wood Preparation	0 - 7500	Log Flume, Log Showers, Hydraulic Debarking, Slucing
Pulping	2000 - 4000	Gland Seal, Condensate Cooling
Pulp Washing	200 - 500	Showers, Dilution
Pulp Screening	0 - 3000	Dilution
Bleaching	3000 -20000	Showers, Chemical Injection
Cleaning and Refining	0 - 7000	Stock Dilution (including 12% offthe washer of decker to 3% machine stock)
Paper Formation	1000 - 4000	Showers, Chemical Injection, Dilution, Seal Water
Pressing	1000 - 6000	Felt Showers, Vacuum Pump Sealing, Gland Seal Water
Finishing	500 - 8000	Repulping Dilution
Liquor Evaporation	1500 -15000	Condensors
Causticing	500 - 3000	Mud Washing, Gas Scrubbers, Dregs Washing
Power Generation	1000 - 3000	Ash Slucicing, Feed Water
Waste treatment	150 - 1500	Filter Backwash, Sluicing
General Washup	500 - 1500	Housekeeping
Cooling	3000 - 6000	Heat Exchangers, Mechanical (Cooling Units, Compressors)

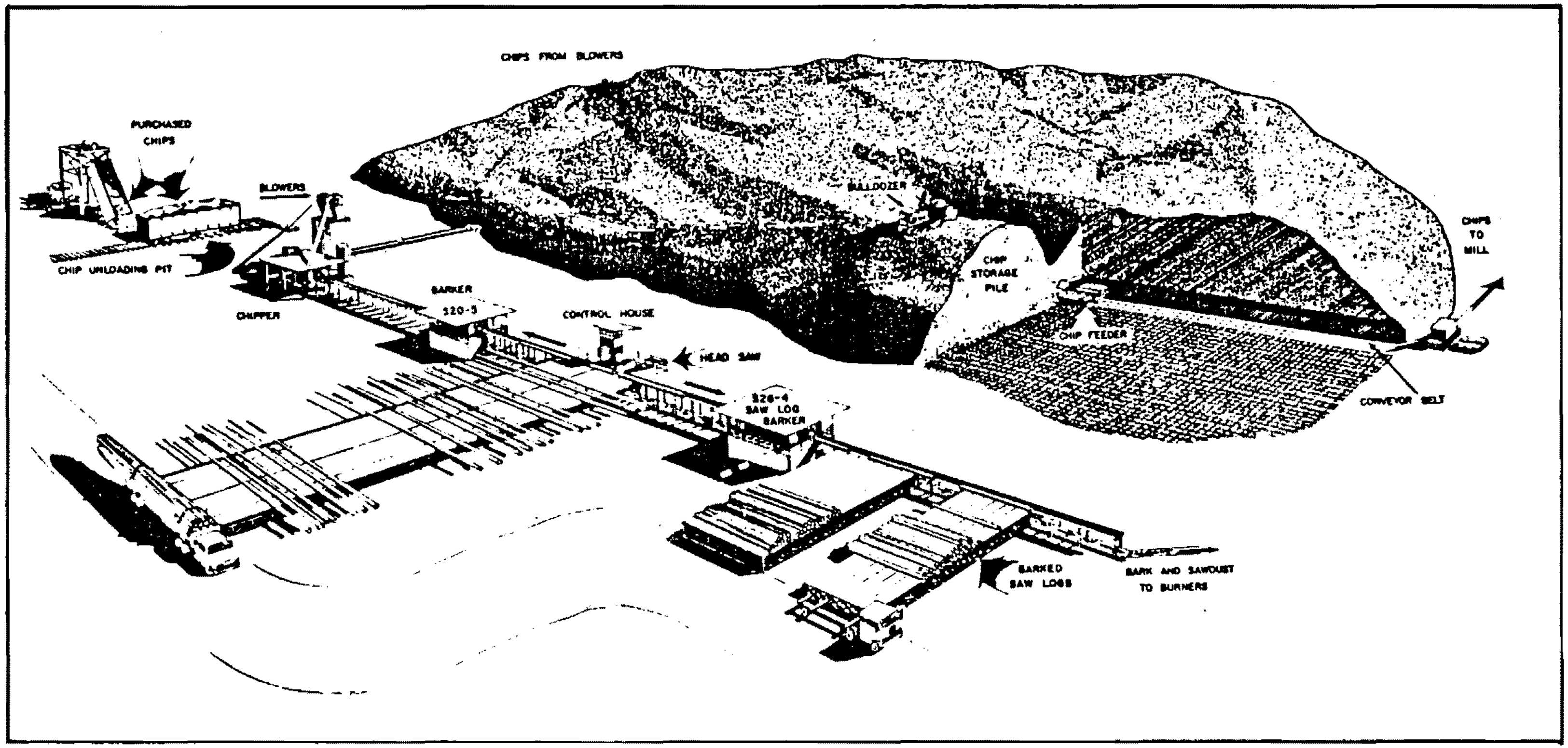


Figure III-1. TYPICAL OUTDOOR WOOD PREPARATION ACTIVITY[3]

- Groundwood Pulping is a process in which fibers are mechanically torn from the sides of short logs through a grinding operation (see Figure III-2) or removed from chips by passing them through a disc refiner (see Figure III-3).

- Chemi-Mechanical Pulping is a process in which chemicals are first used on the wood for softening prior to the performance of groundwood pulping (see Figure III-4).

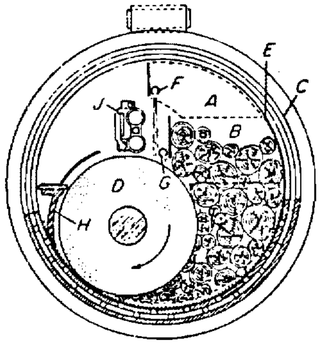
- Kraft or Alkaline Pulping is a process in which wood fibers are freed from their lignin bonds by cooking the wood chips in an alkaline solution of caustic soda (sodium hydroxide) and sodium sulfide (called "white liquor") (see Figure III-5). Kraft pulping is currently the dominant pulping process used worldwide due to the strength of the fibers produced and the economical fashion in which it is performed.

- Sulfite Pulping is a process in which wood fibers are freed from their lignin bonds by cooking the wood chips in a sulfite acid solution (typically made up of sulfur dioxide and water) (see Figure III-6). Unlike the Kraft cooking liquor, from which chemicals can be economically recovered, chemical recovery from sulfite acid cooking liquor has not always been economically attractive and to date, only a limited number of sulfite mills employ a complete chemical recovery system.

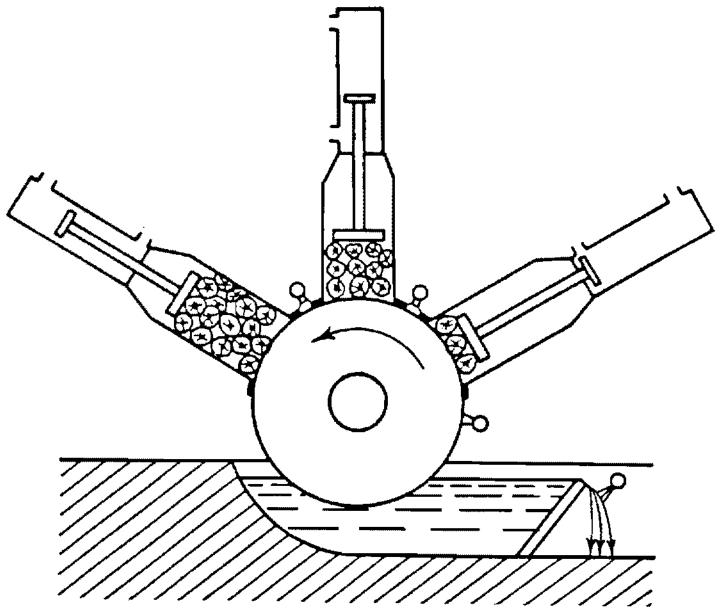
- Semi-Chemical Pulping is a process in which wood chips are cooked with a neutral or slightly alkaline sodium sulfite solution to free fibers from their lignin bond in the wood (see Figure III-7). Semi-chemical pulping is often employed in mills also employing Kraft processing. In such mills the Kraft green liquor can be used as part of the semi-chemical cooking liquor. Liquor recovery systems have been designed and applied to semi-chemical pulping, however, certain liquor combinations have proven difficult in allowing the recovery of sodium sulfite.

Due to the variety of pulping processes available, it is difficult to make a blanket statement regarding water demand. The presence of a suitable liquor recovery system generally reduces water demand, however.

The water demand in pulping can be affected by the type of chemical digestion system employed. Digestors which operate on a continuous basis (see Figure III-8) typically employ less water than digesters operated on a batch basis. This is because of reduced steam and liquor requirements. There are several digestor configurations that can be used including rotary and stationary digestor systems used on batch operations and



RING GRINDER [3]



MULTI-POCKET GRINDER [3]

Figure III-2. WOOD GRINDING TECHNOLOGIES

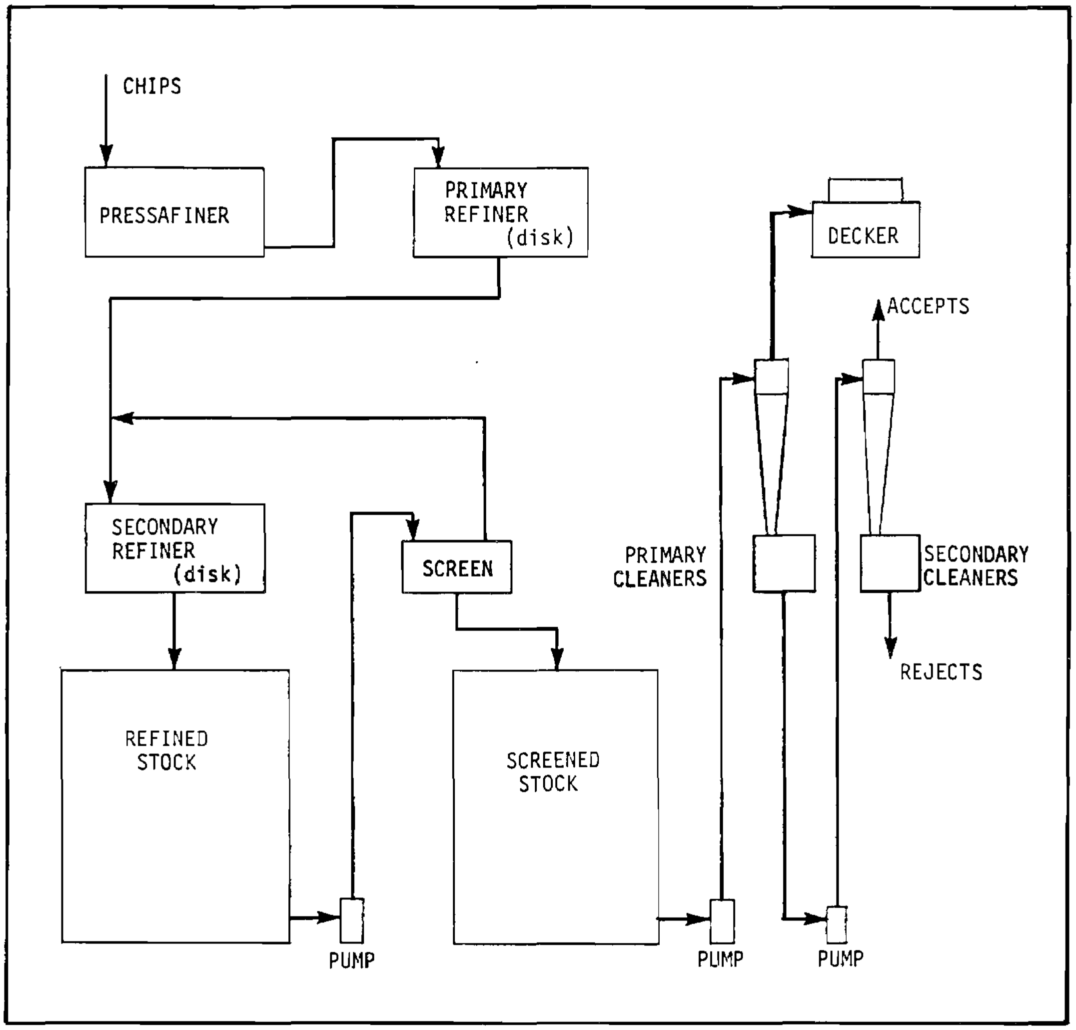


Figure III-3. MECHANICAL PULP FROM CHIPS

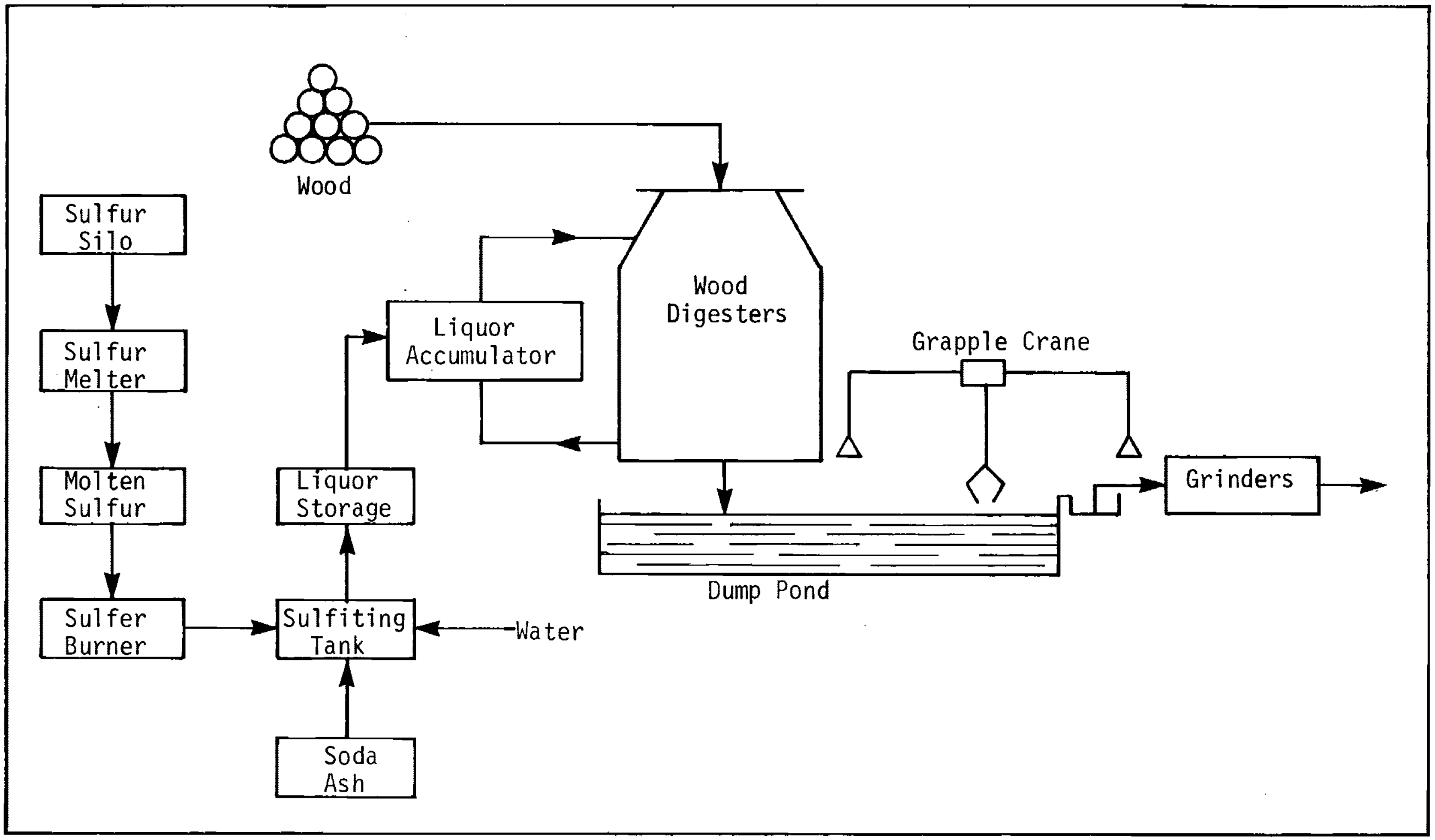


Figure III-4. TYPICAL CHEMI-MECHANICAL PULPING OPERATION

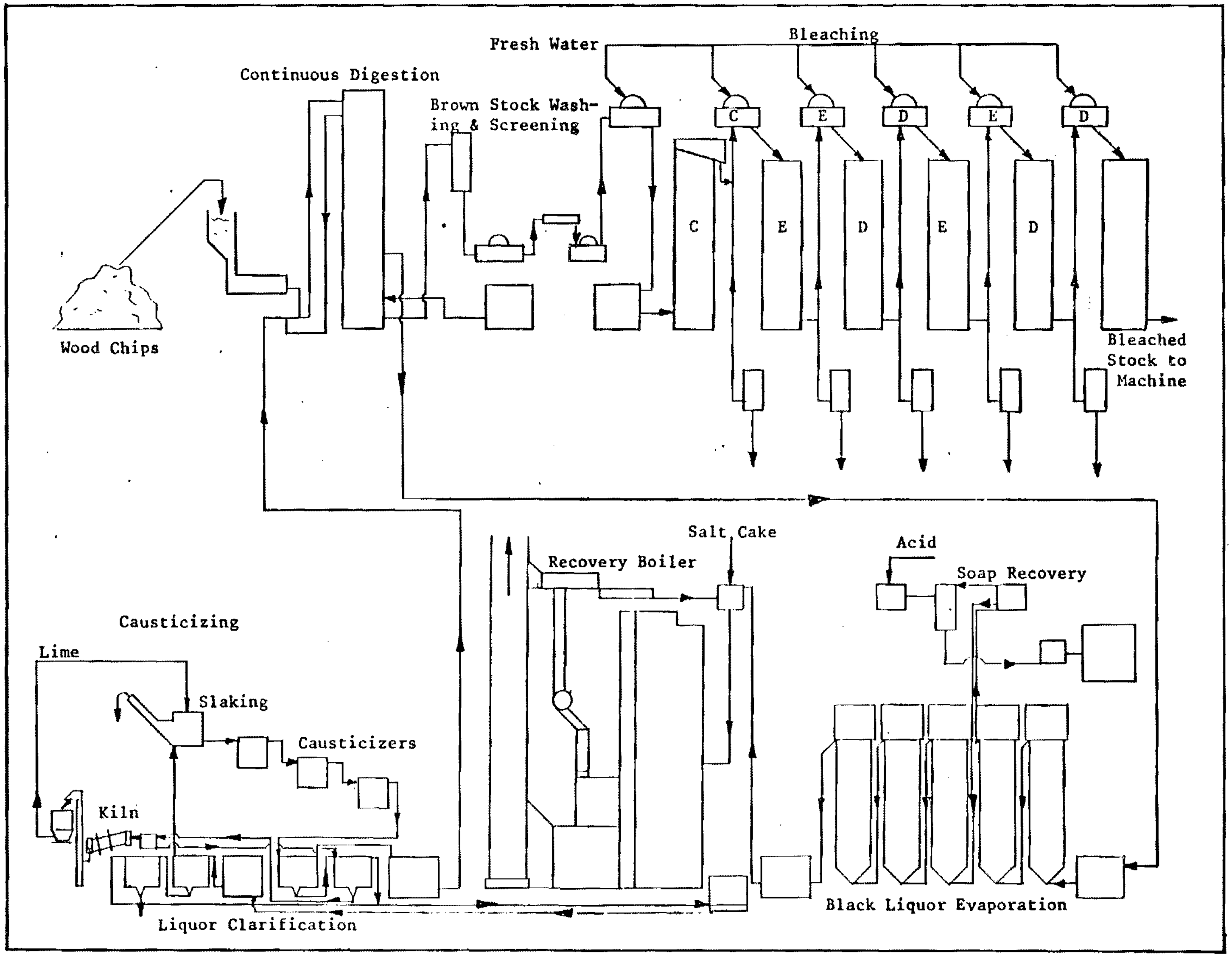


Figure III-5. TYPICAL KRAFT PULPING PROCESS

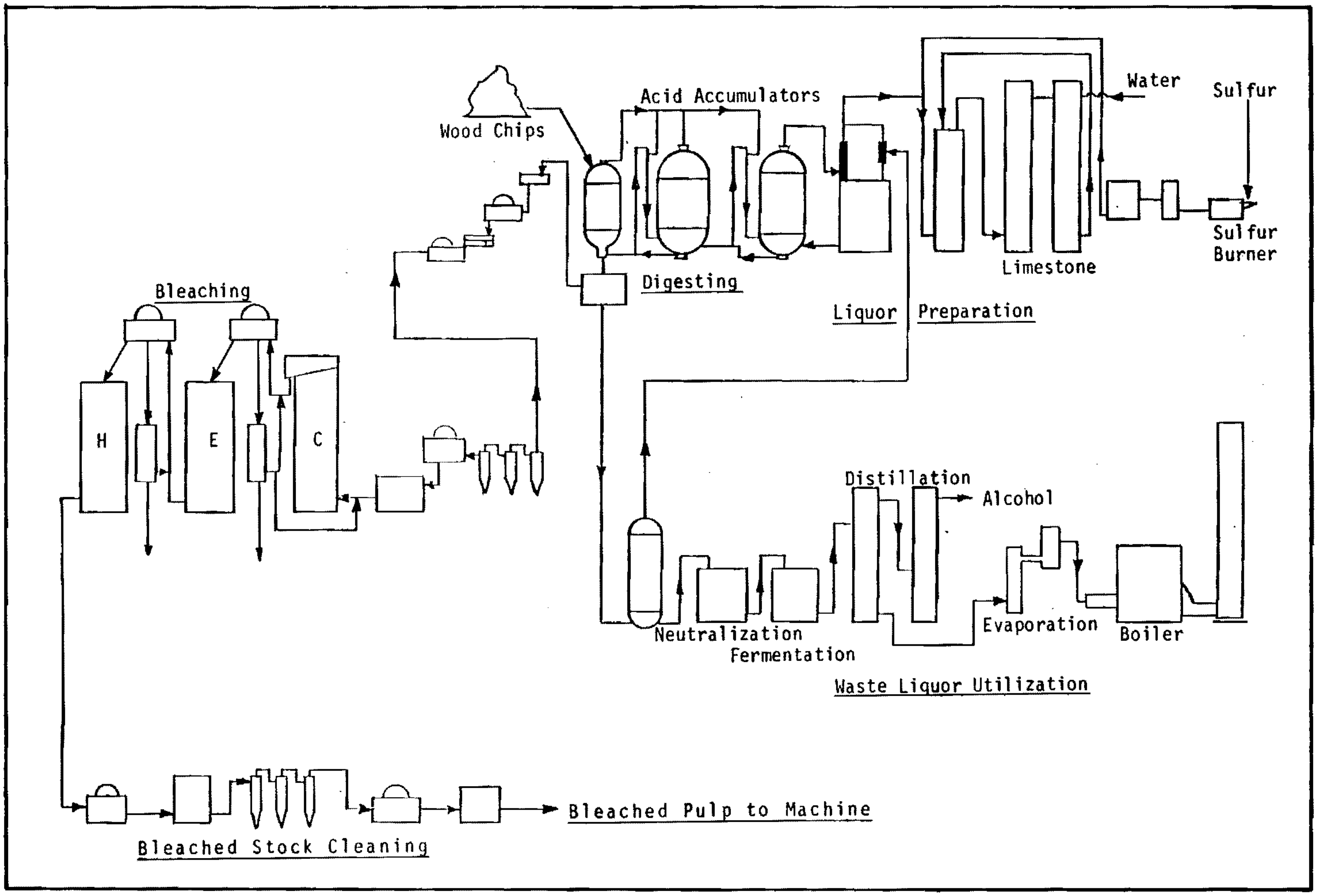


Figure III-6. TYPICAL CALCIUM BASE SULFITE PULPING PROCESS

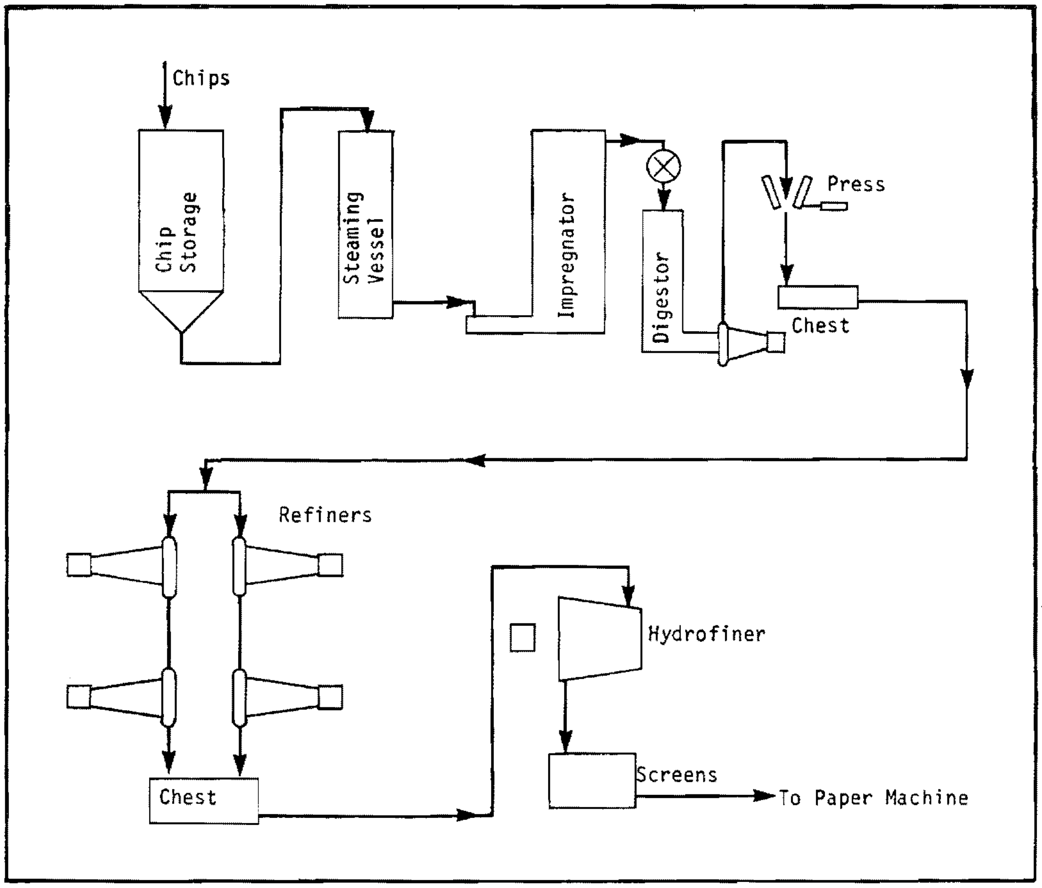


Figure III-7. TYPICAL SEMI-CHEMICAL PULPING

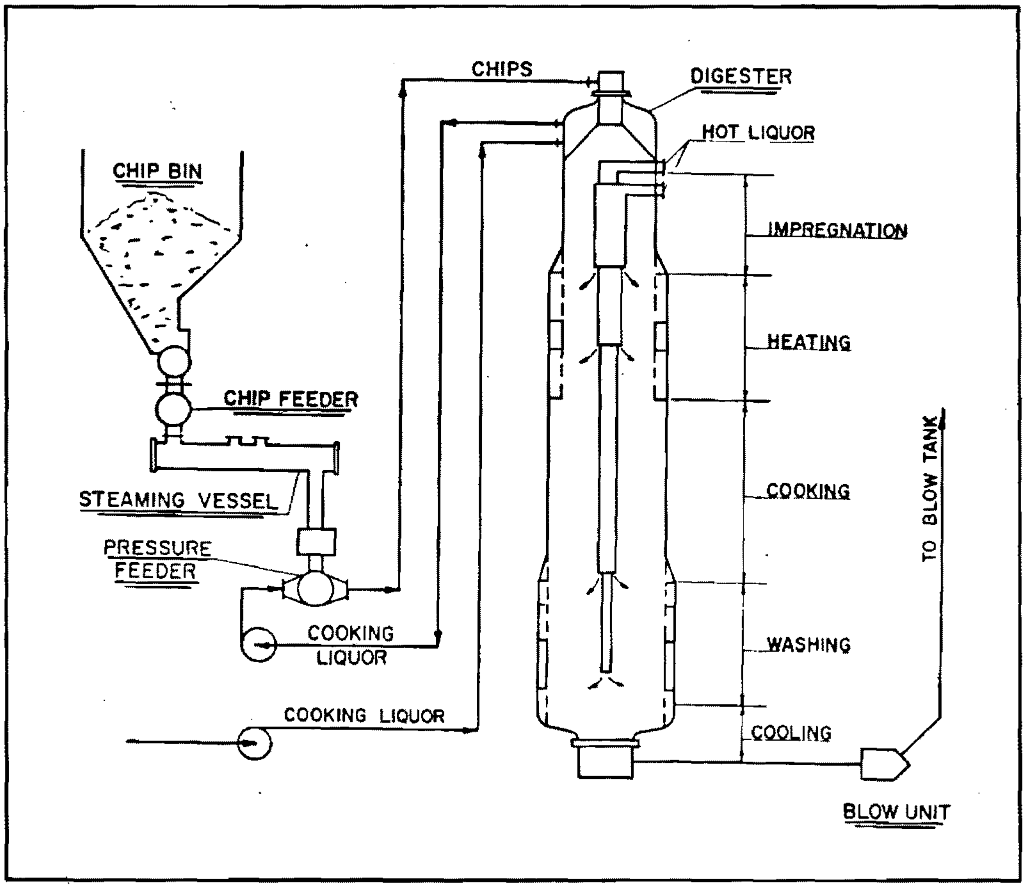


Figure III-8. KAMYR CONTINUOUS KRAFT DIGESTOR[1] horizontal tube, upflow and downflow digestors used on continuous operations. These design differences can also have an impact on water demand.

Pulp Washing[1]

In this operation, the pulp exiting the pulping process is cleaned of foreign matter and cooking liquors. The degree of water demanded depends on the degree of pulp cleanliness sought, with consideration given to any liquor dilution (which must be evaporated or treated).

Washer technologies include vacuum drum washers (see Figure III-9) and displacement washers. The water requirements are similar for both.

Pulp Screening[1]

Screening is performed after the washing stage to remove incompletely cooked knots, chips, and foreign matter that have entered the system. The screening process requires water to dilute the stock for proper screening. Screening technology includes inclined vibratory screens and centrifuge screens (see Figure III-10).

Bleaching[1]

This operation is performed principally to remove all coloring from the pulp fibers. It is accomplished by adding a bleaching agent, which is either an oxidizing compound (the more typical) or a reducing agent. After bleaching, the fibers are thoroughly washed with water to remove impurities. Bleaching agents can vary, but typical compounds used today include chlorine, peroxide, and chlorine dioxide.

The bleaching operation is a very water-intensive operation. Common bleaching processes in use today include both single stage and multistage bleaching (see Figure III-11). Recent breakthroughs in bleaching agent selection have allowed a greatly reduced number of stages to reach a certain brightness for given fiber groups.

Cleaning and Refining[1]

After the pulping process, the fibers obtained are not yet satisfactory for manufacturing paper. To prepare the stock for paper formation, it must be cleaned and refined. Cleaning is usually accomplished by using various centrifugal cleaners and wiretraps which remove heavier fiber particles such as sand and metal filings. The key features of refining pulp include beating the fibers mechanically and adding compounds, such as starches, waxes, and clay, which will ultimately control paper appearance and strength.

Mills which purchase pulp begin this operation by mixing the pulp with water in a process called "repulping". Technologies for repulping typically include large open vat type devices such as the Hydropulper and Quatropulper (see Figure III-12).

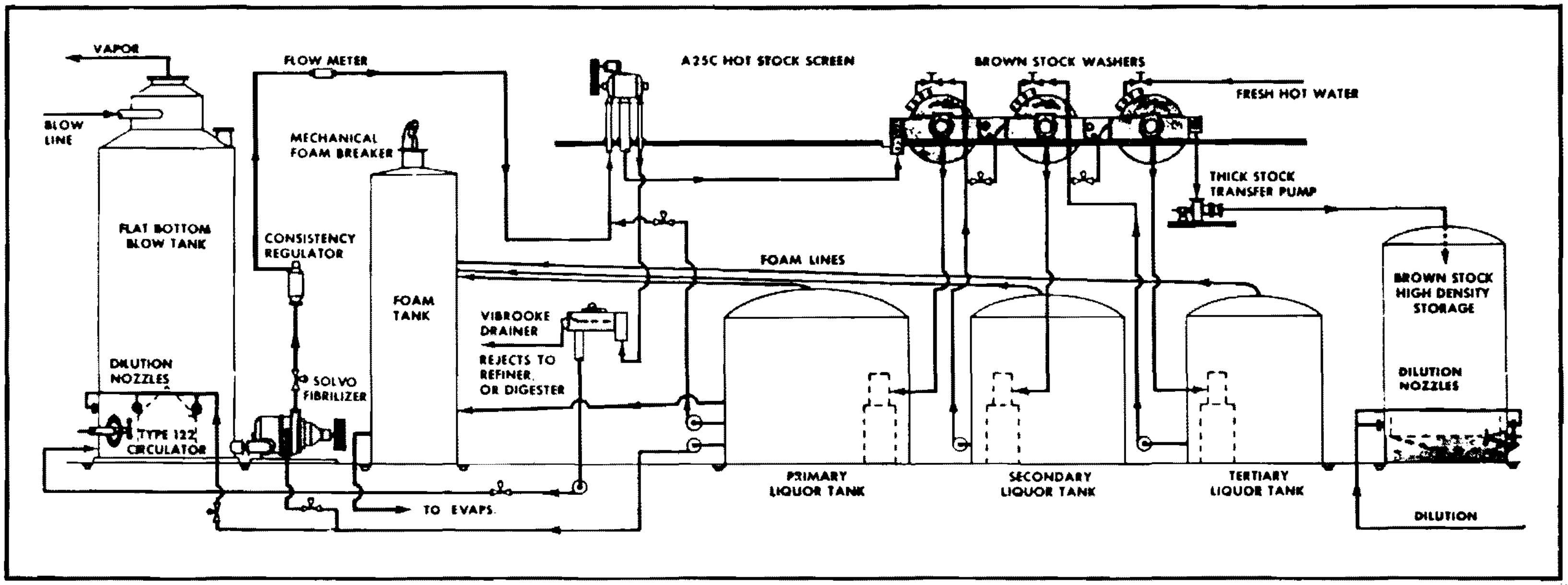
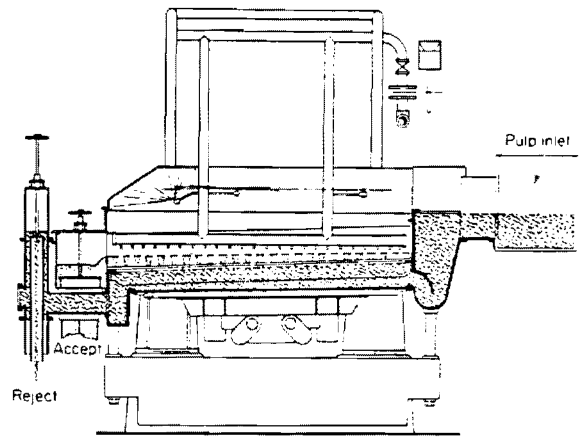
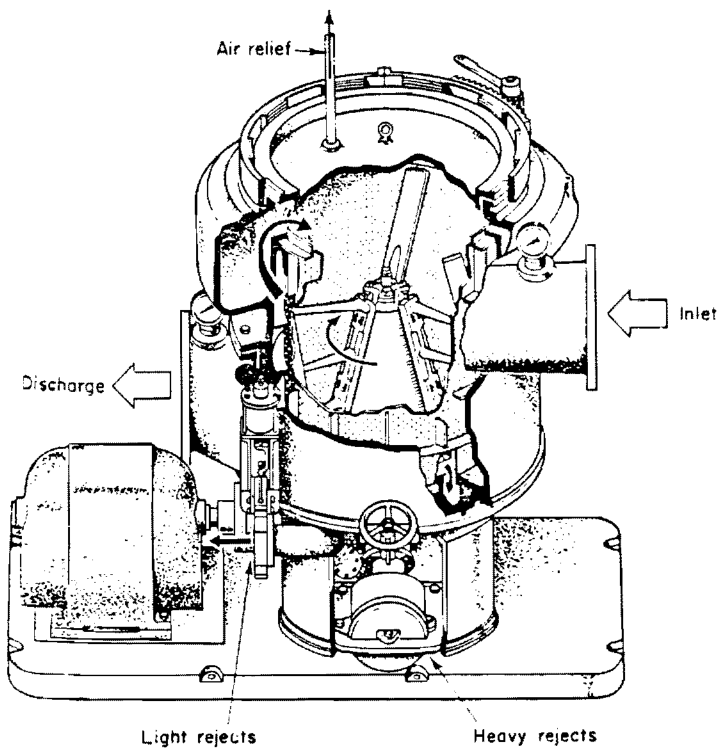


Figure III-9. BROWN STOCK DRUM WASHER SYSTEM [1]



INCLINED VIBRATORY SCREEN[1]



CENTRIFUGE SCREEN[1]

Figure III-10. TYPES OF SCREENING TECHNOLOGY

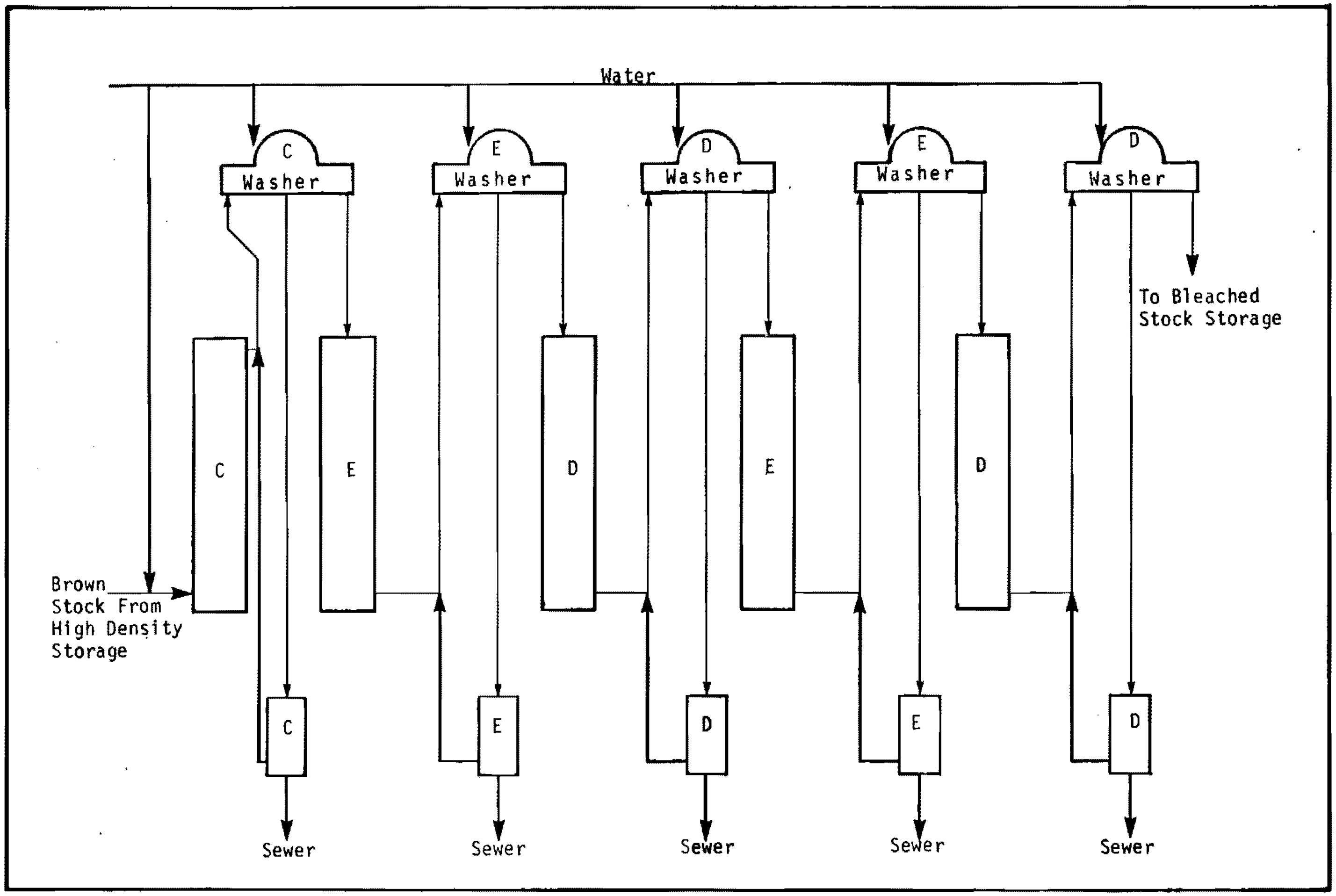


Figure III-11. TYPICAL BLEACHING PROCESS WITH CONVENTIONAL RECYCLE FLOWS HIGHLIGHTED

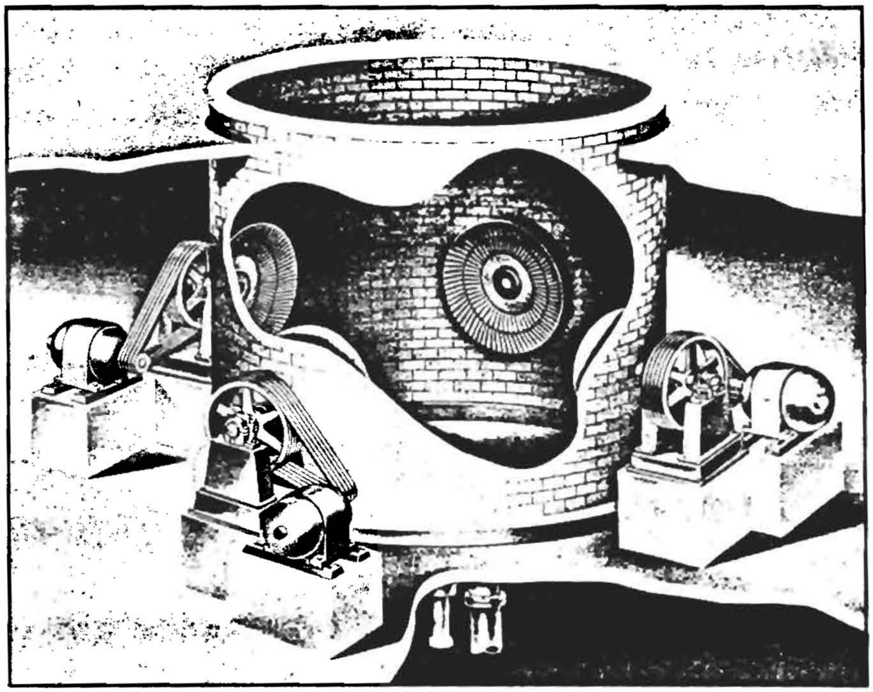


Figure III-12. CUTAWAY VIEW OF A QUATROPULPER [1]

Pulp refining is typically required to shorten fiber length for final product quality. Such refining is performed in refiners, which subject the fibers to intensive mechanical action to break them up. Refiner technology falls into two general classes: conical devices (see Figure III-13) and disc devices.

Water demand is for high dilution in the cleaning and refining operation due to consistency constraints demanded in the paper formation stage that follows. Often, however, this water demand is met substantially by "white water" recovered from the paper making operation.

Paper Formation[1]

As the first step in producing the final paper product, the refined pulp is formed into a thin sheet and dewatered. The forming process typically takes place over a wire screen supported by metal cylinders. The flow of pulp to the screen is handled by a vat or tank which allows it to receive uniform coverage across its entire width.

Two types of paper machines are typically used for forming paper: the fourdrinier and the cylinder paper machines. By far the more commonly employed, the fourdrinier uses an overhead tank (called a head box) at the front of the machine to provide a uniform stock flow to the wire screen table. Once on the forming screen, the necessary water drainage for the pulp is provided by rolls, foils, deflectors, suction boxes, suction rolls, and other such devices. Figure III-14 shows a typical fourdrinier schematic.

The cylinder paper machine, on the other hand, runs the wire screen through a series of forming vats and then controls water drainage from the screen by applying pressure at various points in the drainage cycle through the use of forming cylinders. Figure III-15 shows a typical cylinder machine schematic.

In addition to these two basic forming devices, a group of machines utilizing variations of this forming technology exist. Two notable examples are the "Rotoformer" which is a cylinder variation using series of nozzles to apply the pulp to the forming screen (see Figure III-16) and the "Inverformer" which uses a screen on top of the normal forming screen to squeeze the sheet from both sides for better dewatering (see Figure III-17).

The water demanded in the paper formation process, outside of the required stock consistency for proper formation, results primarily from showers needed to keep the wire and rollers clean from fiber adhesion and foreign substances. Figure III-18 shows the typical placement of showers on a fourdrinier forming table. A variety of shower designs exist to perform this function including such water-saving designs as intermittent, high pressure showers.

As mentioned in the previous section, much of the water demanded in the refining operation is provided by "white water", recovered

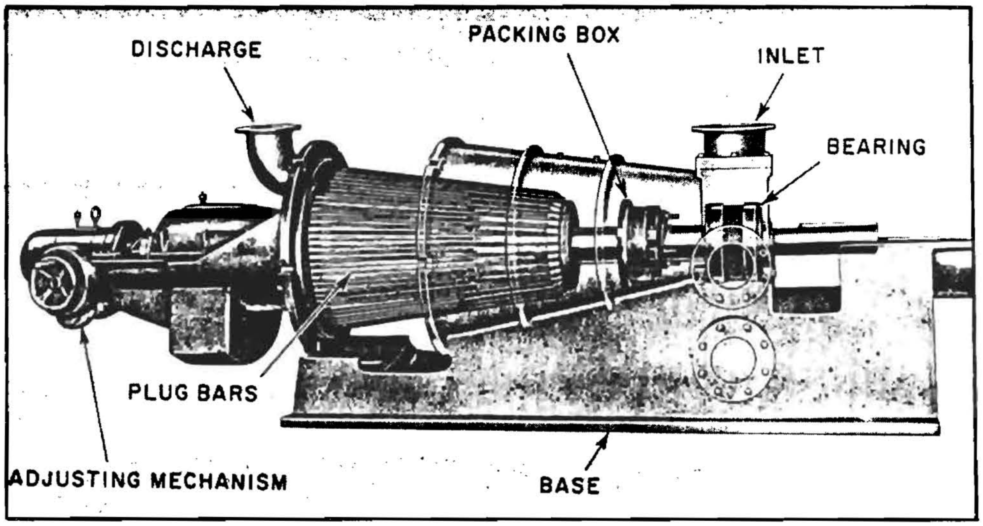


Figure III-13. CUTAWAY VIEW OF A CONICAL REFINER [1]

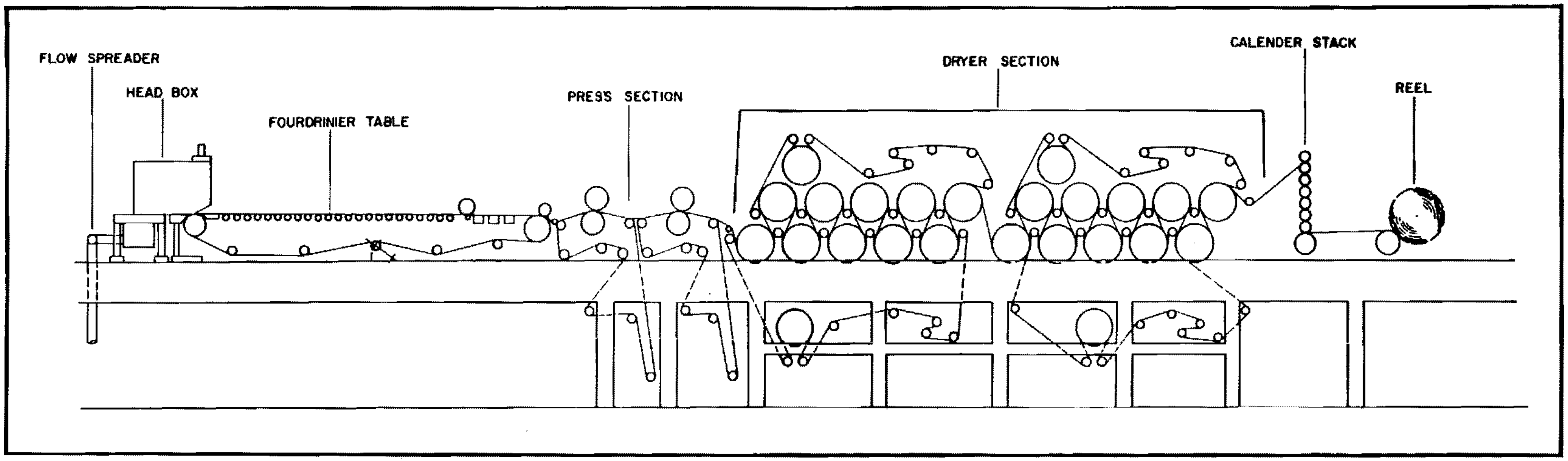


Figure III-14. SCHEMATIC OF A FOURDRINIER PAPER MACHINE [1]

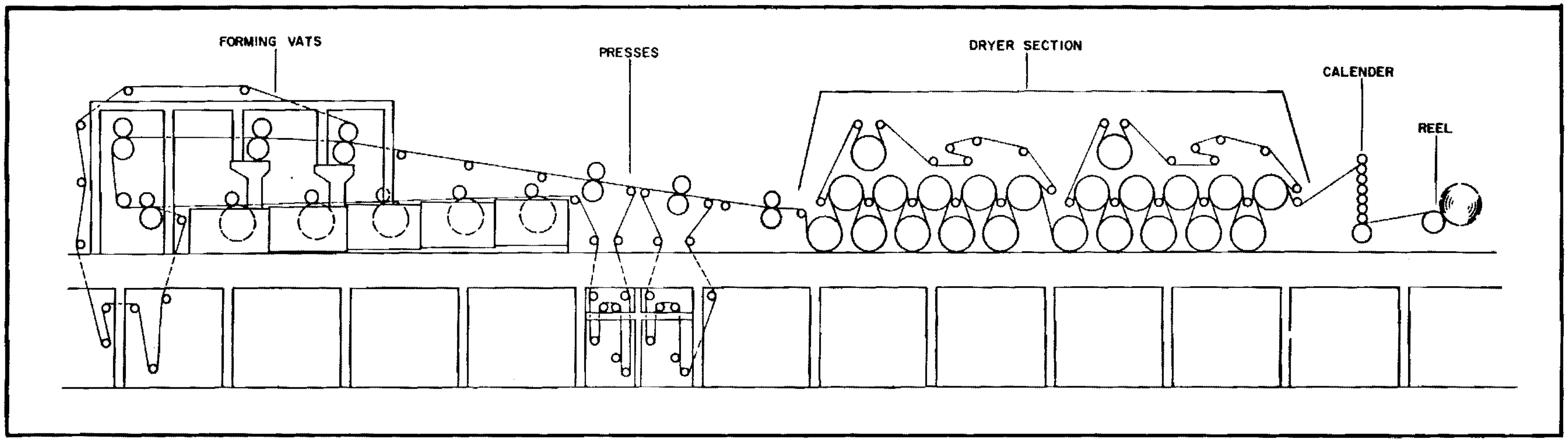


Figure III-15. SCHEMATIC OF A CYLINDER PAPER MACHINE [1]

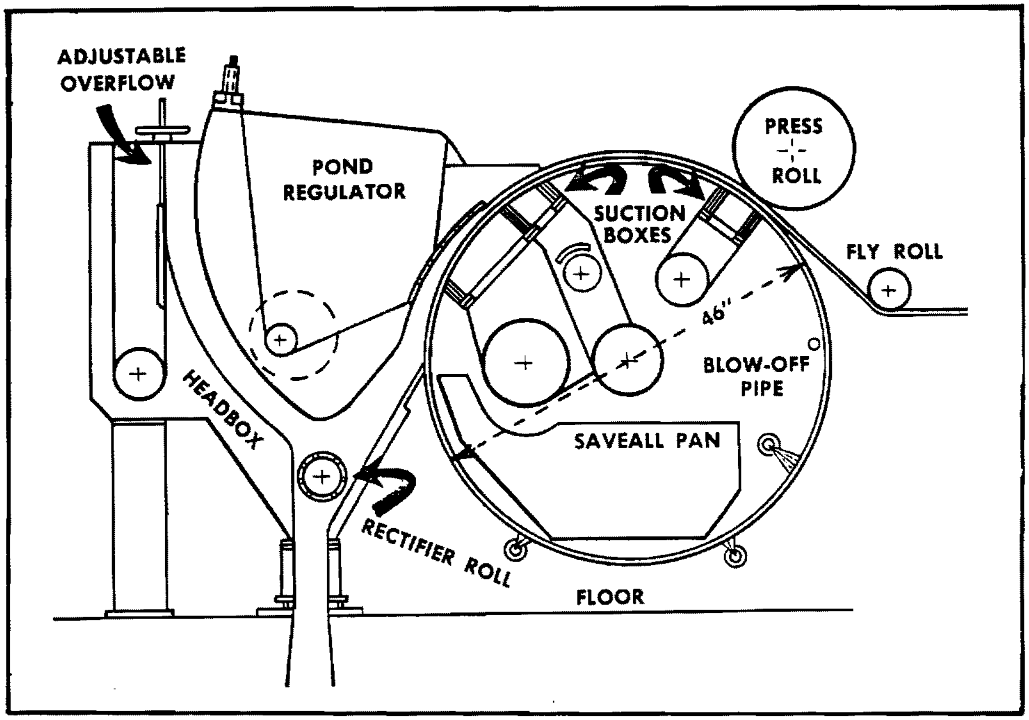


Figure III-16. THE ROTOFORMER [1]

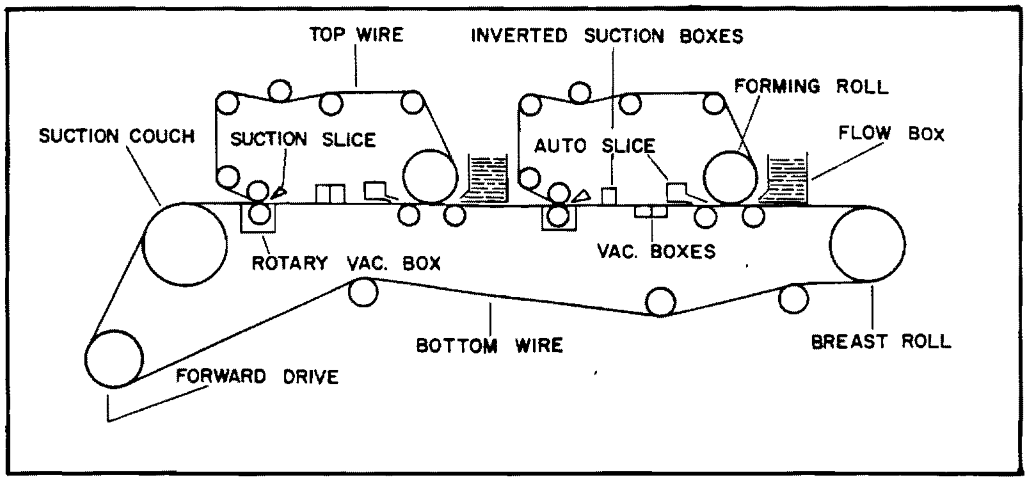


Figure III-17. THE INVERFORMER [1]

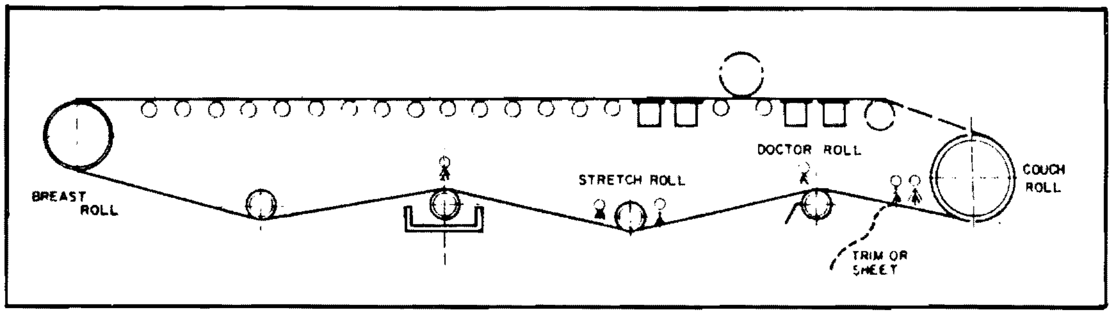


Figure III-18. TYPICAL SHOWER PLACEMENT ON A FOURDRINIER [1]

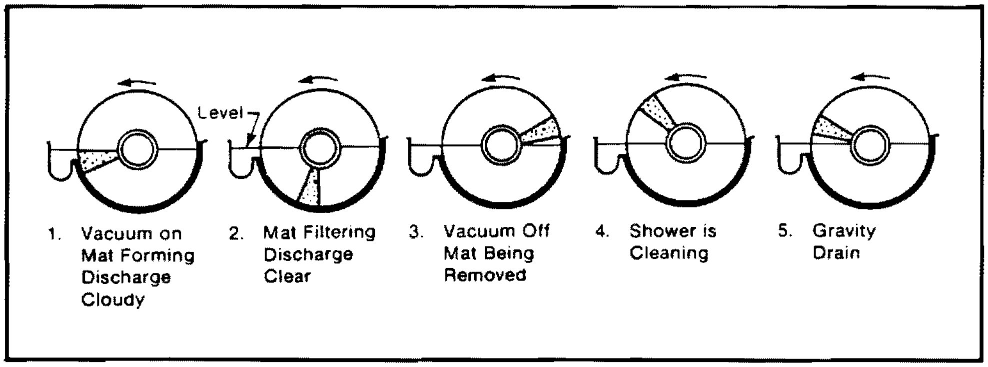


Figure III-19. DISC SAVEALL OPERATING SEQUENCE [1] during paper making. This "white water" is water drained from the pulp as the paper sheet is formed and subsequently pressed. Much of the water is recycled to the beginning of the paper formation process but a portion is sent through a screening device called a saveall, which separates fiber from water. This operation allows clarified white water recovered from the paper formation to be used for showering and other purposes. Saveall technologies include clarifier systems, perforated drum systems, and perforated disc systems, each having their own advantages in terms of size, efficiency, and plugging characteristics. Figure III-19 shows the operating sequence for a disc saveall. Figure III-20 displays a typical system design for the recovery of white water.

Pressing[1]

Once the paper sheet is formed on the wire, it is still roughly five parts water to one part fiber and must be further dewatered through mechanical means. The sheet is transferred to the press section by the couch roll where it is placed on press felts and run through a series of cylinders. The press section typically reduces the water content of the paper sheet to about three parts water to one part fiber. Figure III-21 shows some common pressing techniques used to accomplish this activity.

Water demand in the press section is primarily due to felt showers used to clean the felt-carrying medium after it has conveyed the paper sheet through the press section. This cleaning opens up the felt pores to enable them to remove water efficiently by removing contaminants such as pitch sizing, silt, mineral particles, fillers, and pulp fibers. Because of the importance of thoroughly cleaning felts, freshwater is frequently used on felt showers. Typical pressing technologies include the roller press and the Yankee machine (for tissue) (see Figure III-22).

Drying[1]

After thoroughly pressing the paper sheet, there is still a significant amount of water in the paper sheet (roughly 65% moisture content). This remaining moisture is removed in the drying section where the sheet is typically passed over a series of steam-heated rolls to achieve the desired final moisture content of about 6%. The paper sheet is held tightly against the drying cylinder by a dryer felt which also helps in threading the paper through the dryer section (see Figure III-23). The primary water demand in the drying process is steam used to heat the various drying cylinders.

Unlike in the press section, water is not used in dryer felt cleaning. Typically air is used to clean and aid in keeping the moisture content to acceptable levels. Other drying technologies include devices which do not employ felts but rather make use of high velocity air to scrub the moisture from the surface of the sheet.

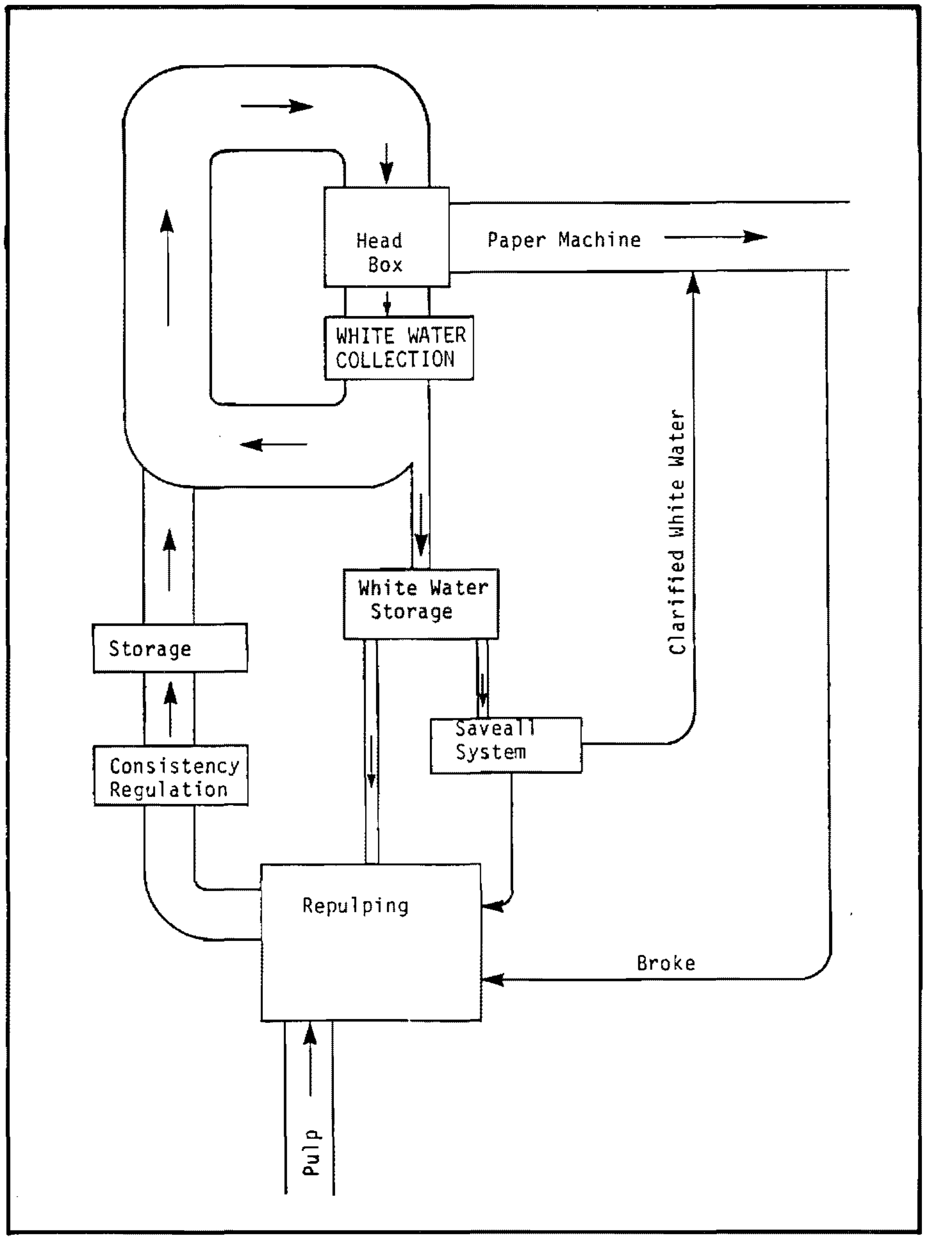


Figure III-20. TYPICAL WHITE WATER RECOVERY SYSTEM [1]

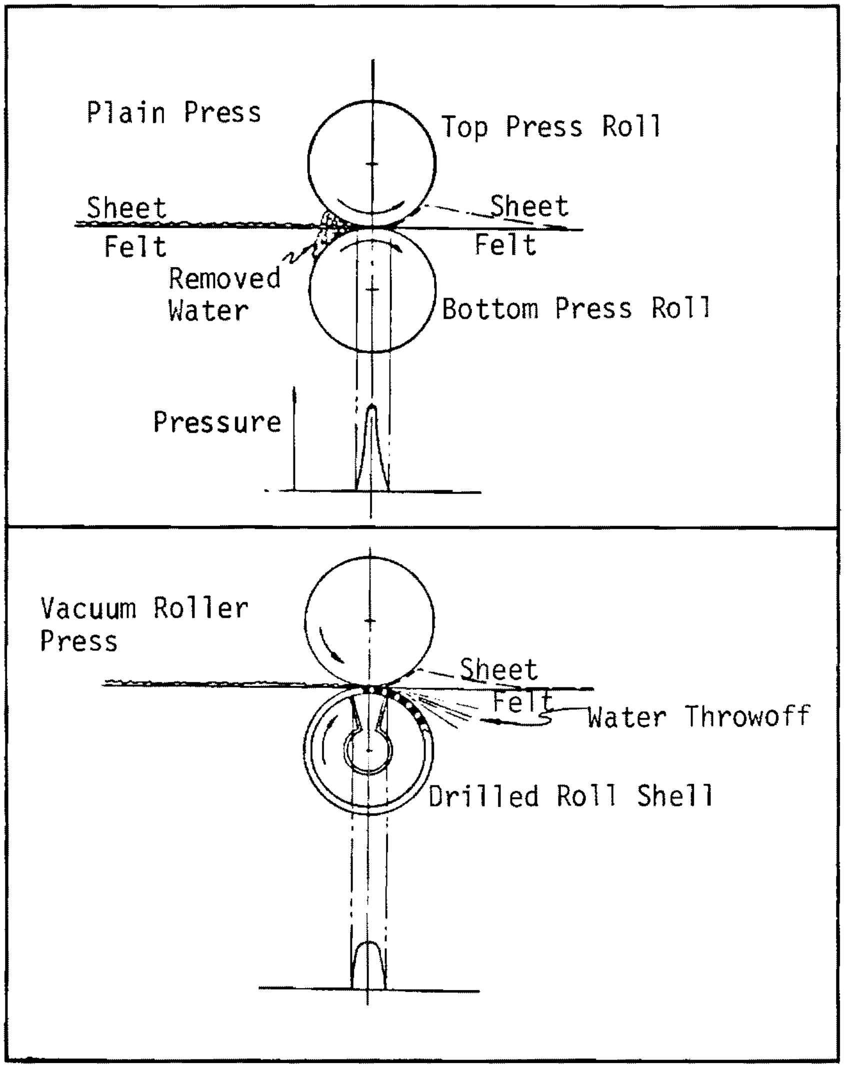


Figure III-21. TYPICAL PRESSING TECHNIQUES [1]

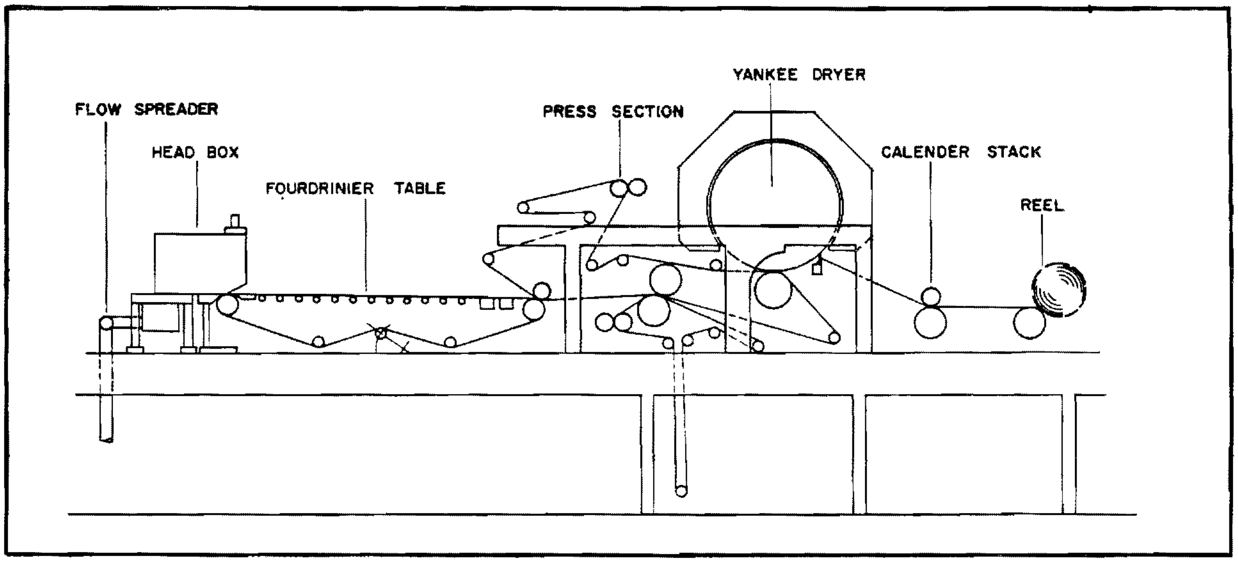


Figure III-22. YANKEE PRESSING MACHINE [1]

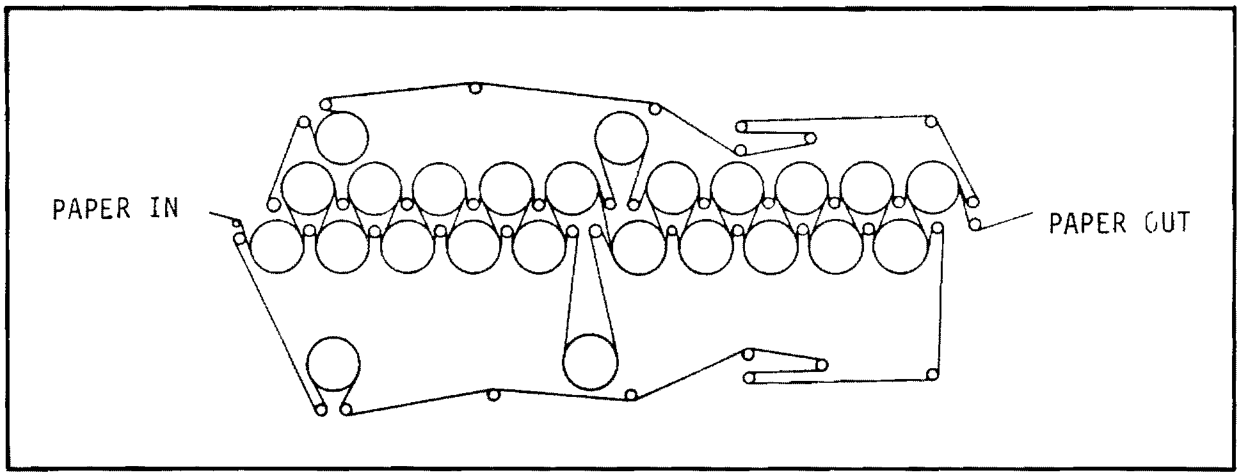


Figure III-23. TYPICAL DRYER SECTION ON PAPER MACHINE [1]

Finishing[1]

Once the paper sheet has achieved its final moisture level, it is ready for various finishing operations. First the sheet is wound in a roll, then rewound while being split into smaller widths. Then a coating is added to achieve the desired finish. There are several different coating techniques that can be employed in finishing operations but the most common is the roll coater. Three techniques for coating a roll are shown in Figure III-24. In the coating operation, the moisture content of the paper sheet can rise to 20% due to the water-based coating mixture applied. This excess moisture is typically removed using a series of dryers on the back end of the finishing press.

Liquor Evaporation[1]

In the Kraft pulping process, liquor recovery is an integral part of the operation. The first step is to recover the spent liquor (termed "black liquor") and to concentrate this liquor by passing it through a series of multiple-effect and direct contact evaporators. The concentrated liquor is then incinerated in a recovery furnace together with a salt cake. The salt cake is used to make up for sodium losses in the incineration process (see Figure III-25). The resultant smelt from the furnace is then ready for causticizing.

The liquor evaporation process demands considerable water to cool the black liquor evaporator condenser. A significant volume of water is removed from the liquor in the evaporation stage which may be recoverable for other uses.

Causticizing[1]

Once the Kraft black liquor has been reduced to smelt in the recovery furnace it is then dissolved in water to form what is called "green liquor". In the causticizing operation, the green liquor is treated with lime to convert the sodium carbonate to sodium hydroxide. The resulting liquor solution, after lime removal, is called "white liquor" and is of suitable quality for reuse in the digestor. Figure III-26 shows a typical causticizing operation.

Water demanded in the causticizing process is primarily for forming the green liquor and for washing various wastes leaving the process in order to recover adhering chemicals. The lime used in the causticizing process is recovered in a lime kiln where, as in the recovery furnace, excess water is driven off.

Chlorine Dioxide Production[1]

For plants using chlorine dioxide in their bleaching operation, this gas is generally produced on-site and close to its point of use due to its hazardous nature. A variety of production techniques exist for generating chlorine dioxide most of which require water. Further, cooling water is required for refrigeration processes. The process

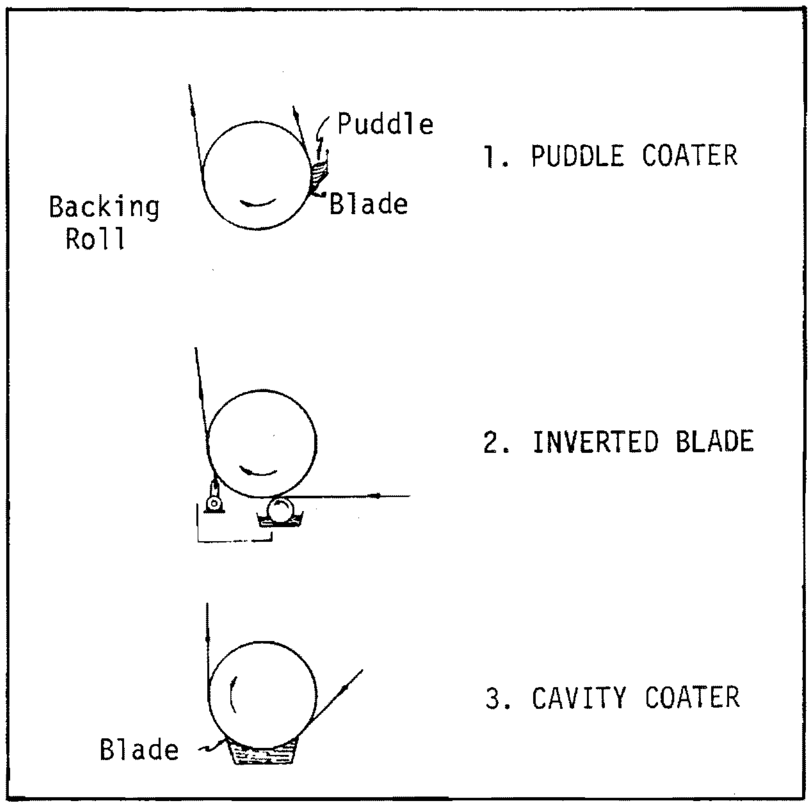


Figure III-24. COMMON ROLL COATING TECHNIQUES [1]

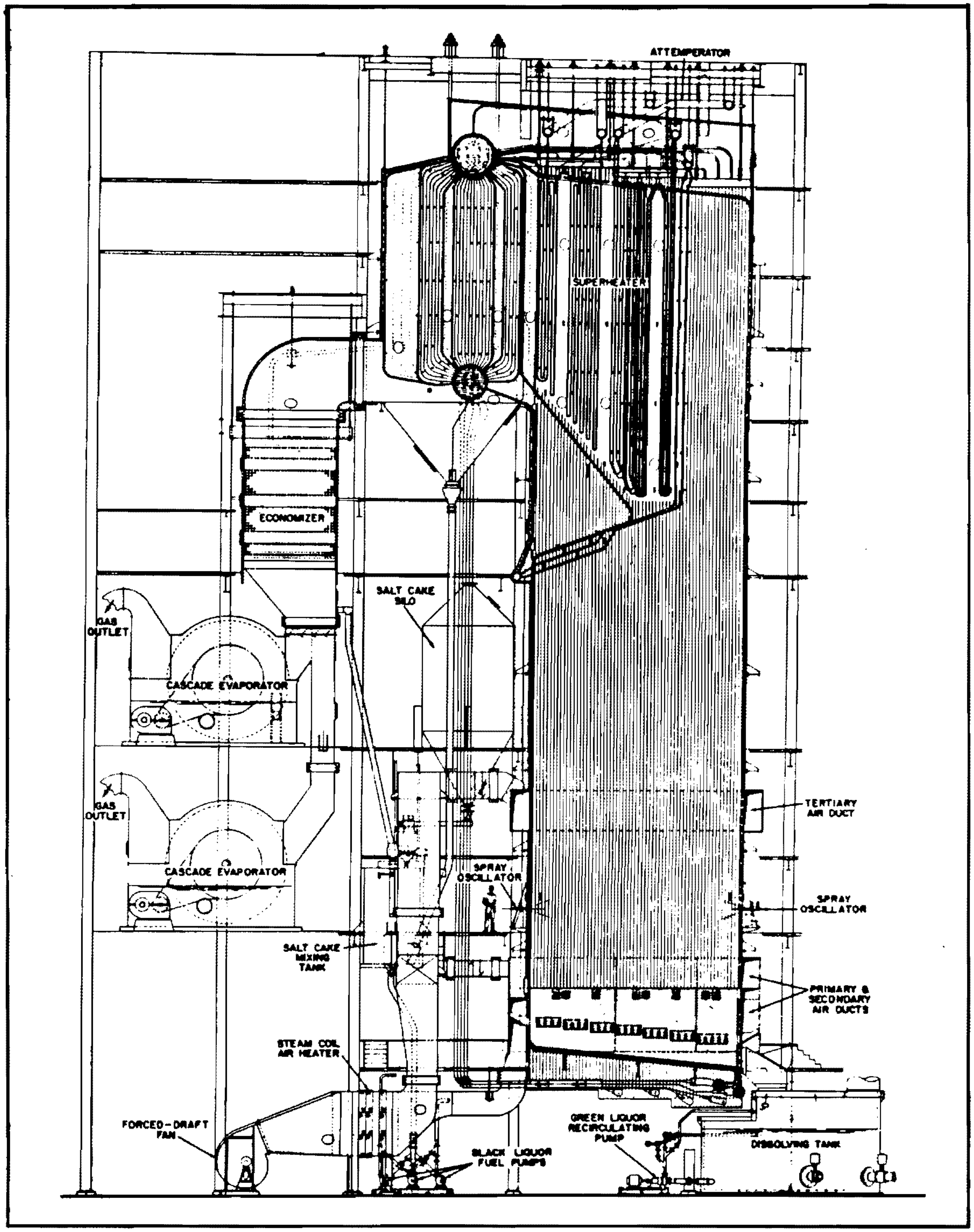


Figure III-25. BLACK LIQUOR RECOVERY FURNACE [1]

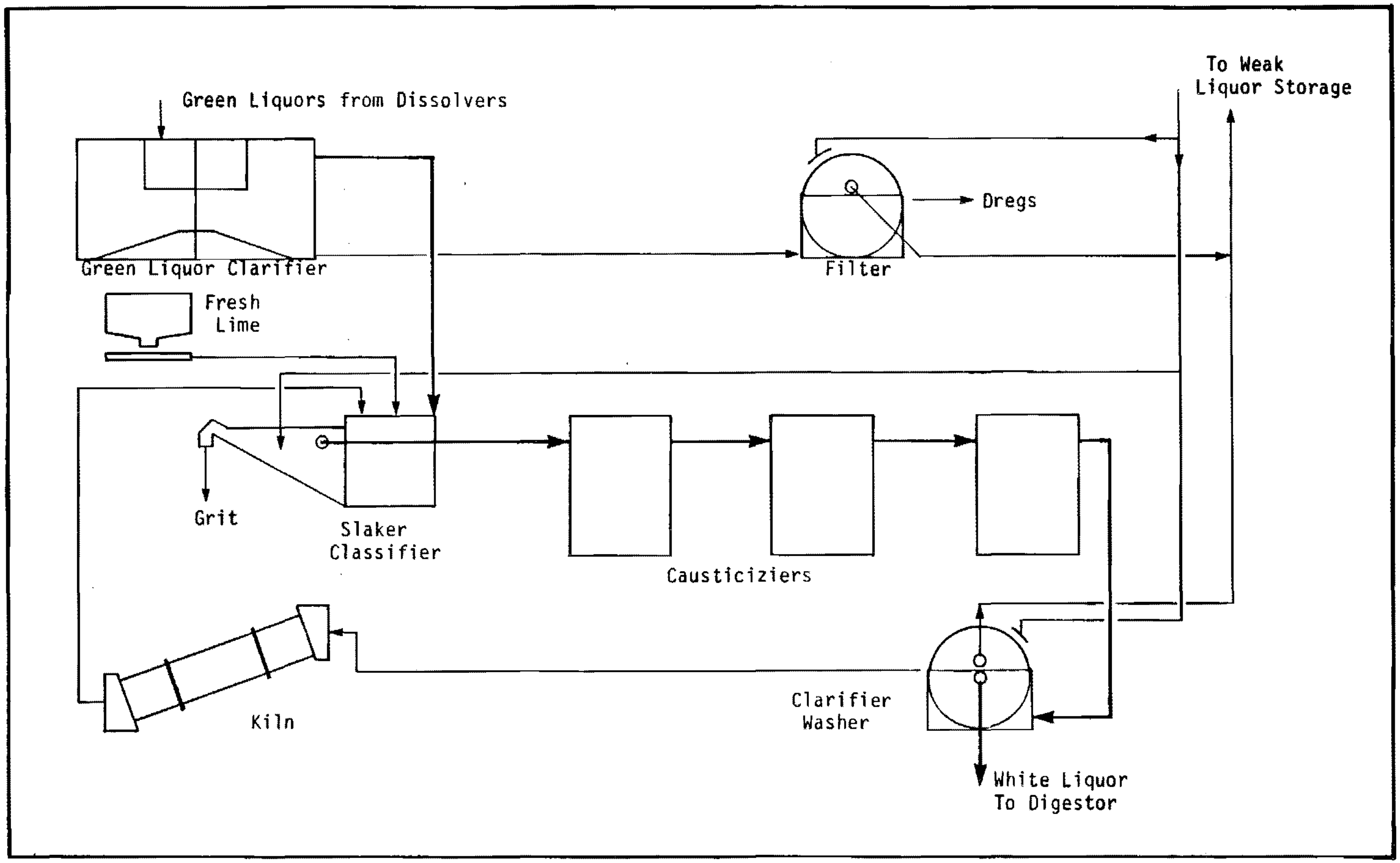


Figure III-26. TYPICAL CAUSTICIZING OPERATION variations that exist revolve primarily around the type of reducing agent selected.

Power Generation and Cooling

Common to all mills is the generation of steam, compressed air, and electricity and the supplying of cooling water for use throughout the production operations. Mill power plants typically have a substantial water demand primarily to generate steam and to meet cooling needs. The water demand for steam generation is sometimes partially met by recovering steam condensate from steam traps, heat exchanger discharges, and dryers throughout the mill. Cooling water demand can be handled either from fresh incoming water or from water recycled through cooling ponds or towers.

Waste Treatment

Wastewater received from the production operation is sewered to a treatment facility for processing prior to releasing to a natural body of water. The wastewater must often be screened first to remove materials that might plug or damage treatment equipment. Automatically cleaned screens are the most widely used for such purposes. Following this screening a primary treatment process is used to remove organic or inorganic suspended solids. Devices available for such treatment include mechanical clarifiers, flotation units, or sedimentation lagoons. The most common treatment technique used by pulp and paper mills is mechanical clarifiers. Figure III-27 shows the typical design of such a system.

Secondary treatment of the wastewater following primary treatment is typically required to further reduce the pollutant load. The principal benefit from secondary treatment is to reduce the biological oxygen demand (BOD_5) of the waste stream. Techniques for accomplishing this include oxidation lagoons, aerated stablization basins, and activated sludge processes. The first two techniques are frequently used because of their low costs. They involve large, shallow lagoons which allow the wastewater to interact with air, the latter using mechanical aeration techniques to enhance this process. Their major drawback, however, is the large acreage typically demanded. The third technique is an accelerated biological treatment process whose chief advantage is the compactness of the system and the relatively short detention time needed to effectively treat waste (see Figure III-28).

Water demand in the wastewater treatment process is typically satisfied by recycling process water being treated. However, the treated effluent discharged from the waste treatment plant offers a significant potential source of water for reuse either by the mill discharging it or by a neighboring operation able to use water of such quality.

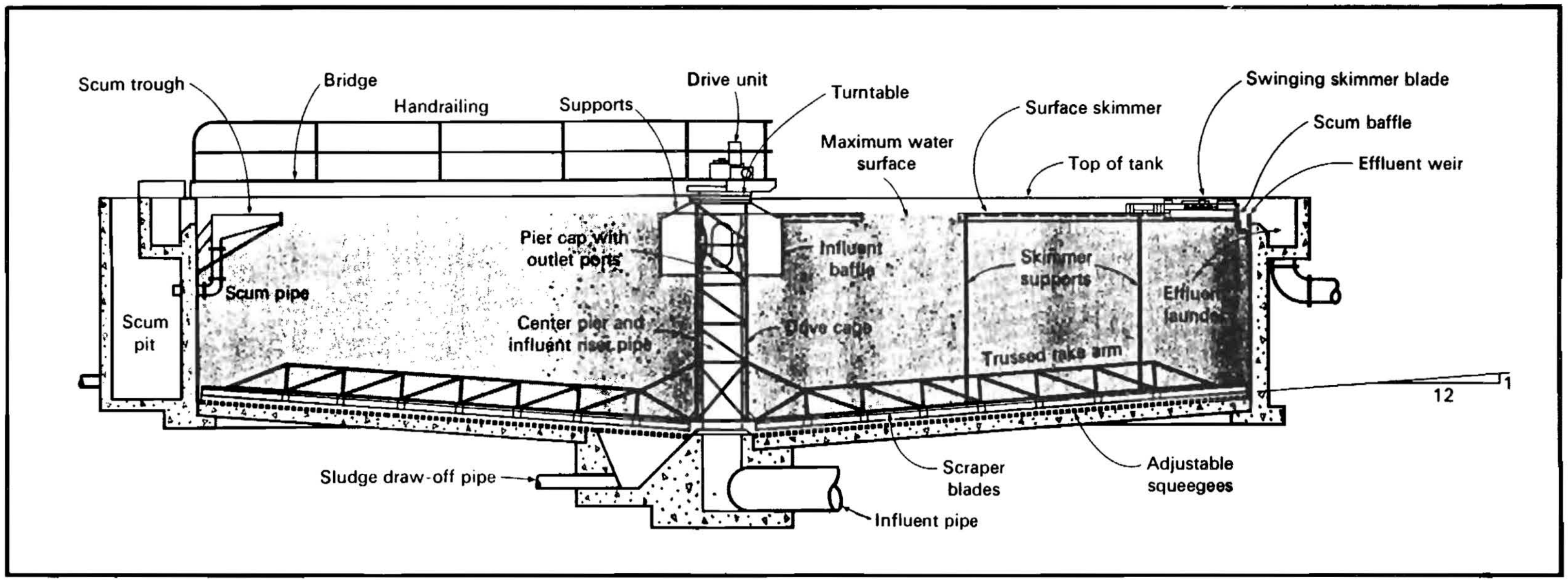


Figure III-27. MECHANICAL CLARIFIER DESIGN [10]

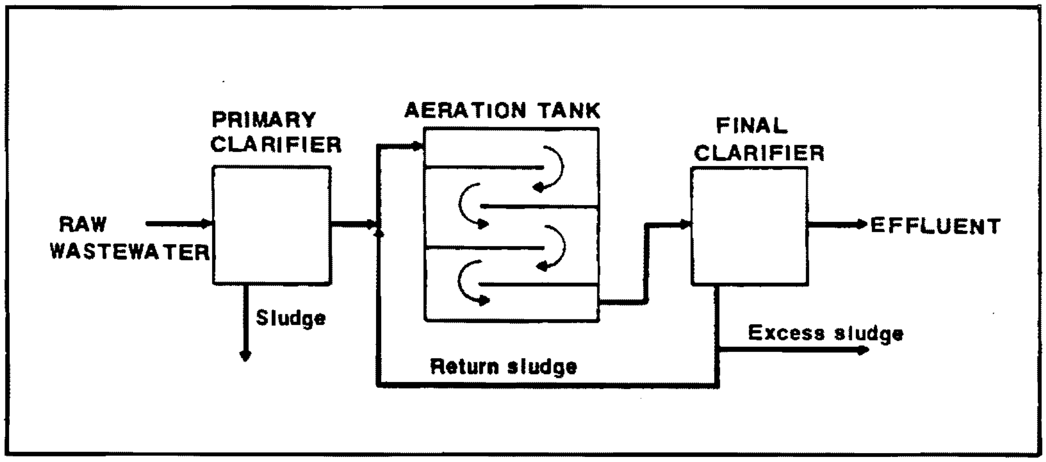


Figure III-28. CONVENTIONAL ACTIVATED SLUDGE FACILITY [10]

PROCESS SYSTEM IDENTIFICATION

As discussed in Section II, ten major pulp and paper industry subcategories were selected for detailed evaluation in this study. For reference, these were:

- Dissolving Kraft
- Market Bleached Kraft
- BCT Bleached Kraft
- Alkaline Fine
- Unbleached Kraft
- Unbleached Kraft and Semi-Chemical
- Dissolving Sulfite Pulp
- Papergrade Sulfite
- Integrated Miscellaneous Mills
- Nonintegrated Fine Papers

To facilitate systems analysis, each industry subcategory was assembled into a series of the production subprocesses described earlier. This assemablage resulted in a group of process "trains" for each subcategory, suitable for use in evaluating reuse/recycle options. Below is a presentation of the process "trains" developed for the above subcategories together with a brief explanation of process uniqueness and the typical water demands of each.

Dissolving Kraft - Figure III-29 presents the typical process "train" for dissolving bleached Kraft operations. This production category calls for the development of a uniquely high grade of pulp free from lignin carbohydrates and wood sugars. Because washing, cleaning, and bleaching must be very thorough, large amounts of freshwater are typically employed. Mills producing this grade of pulp sell it in pulp form and therefore many of the chemical compounds and finishing techniques used for paper production are absent in these mills. Table III-2 shows the typical water demands for this category.

Market Bleached Kraft - Figure III-30 presents the typical process "train" for market bleached Kraft operations. Unlike other integrated pulp and paper productions, market bleached Kraft mills do not produce a commercial grade of paper. Rather these mills produce a bleached pulp which is sold for use by others in their paper-making operations. The pulp is typically sold in sheet bales or rolls of either low (6-8%) or high (30-45%) moisture content. The latter form, called "wet lap", is only suitable for limited shipping distances because of the excess weight provided by the water. Table III-3 shows the typical water demands for this category.

BCT (Board, Course, and Tissue) Bleached Kraft - Figure III-31 presents the typical process "train" for BCT bleach kraft operations. This category covers the production of most commercial paper grades except for fine papers, and also includes mills producing market bleached Kraft as a part

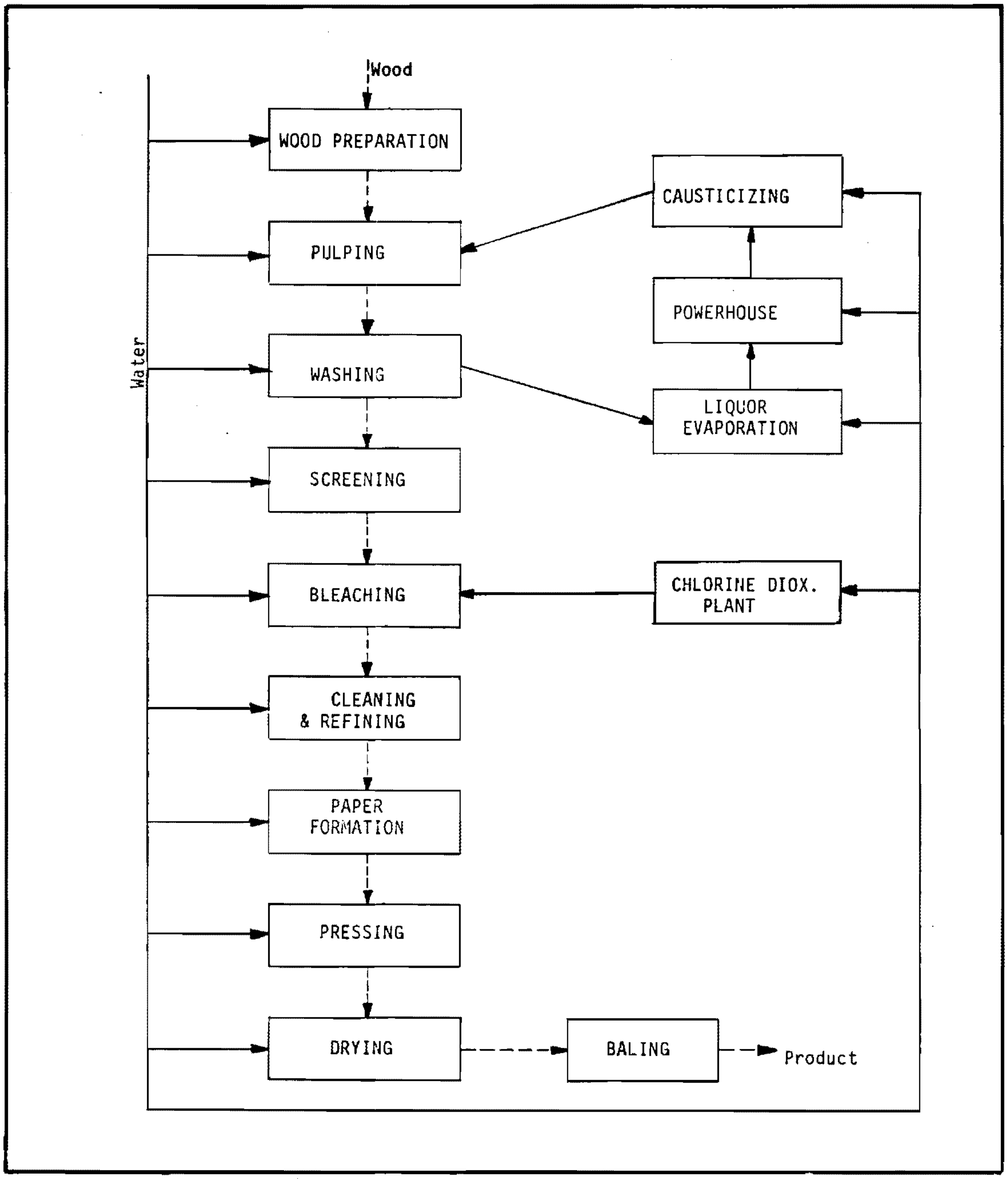


Figure III-29. PROCESS FLOW DIAGRAM FOR DISSOLVING BLEACHED KRAFT

Table III-2. DISSOLVING BLEACHED KRAFT STATISTICS

Number of mills	3
Total production	3,350 tpd
Total water	148 mgd
Average water	44,180 gallons/ton

Table III-3. MARKET BLEACHED KRAFT STATISTICS

Number of mills	7
Total production	5,195 tpd
Total water	161 mgd
Average water	35,000 gallons/ton

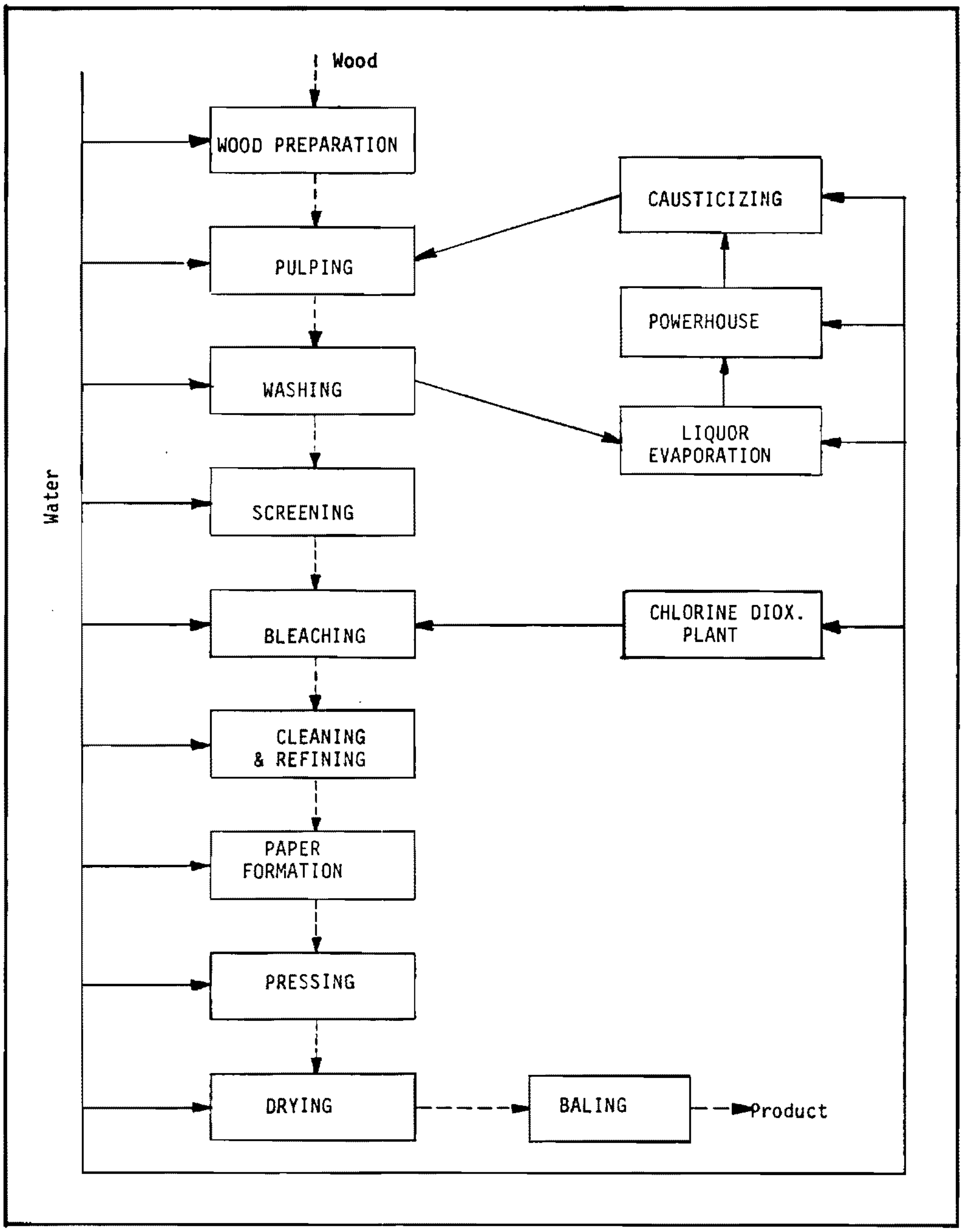


Figure III-30. PROCESS FLOW DIAGRAM FOR MARKET BLEACHED KRAFT

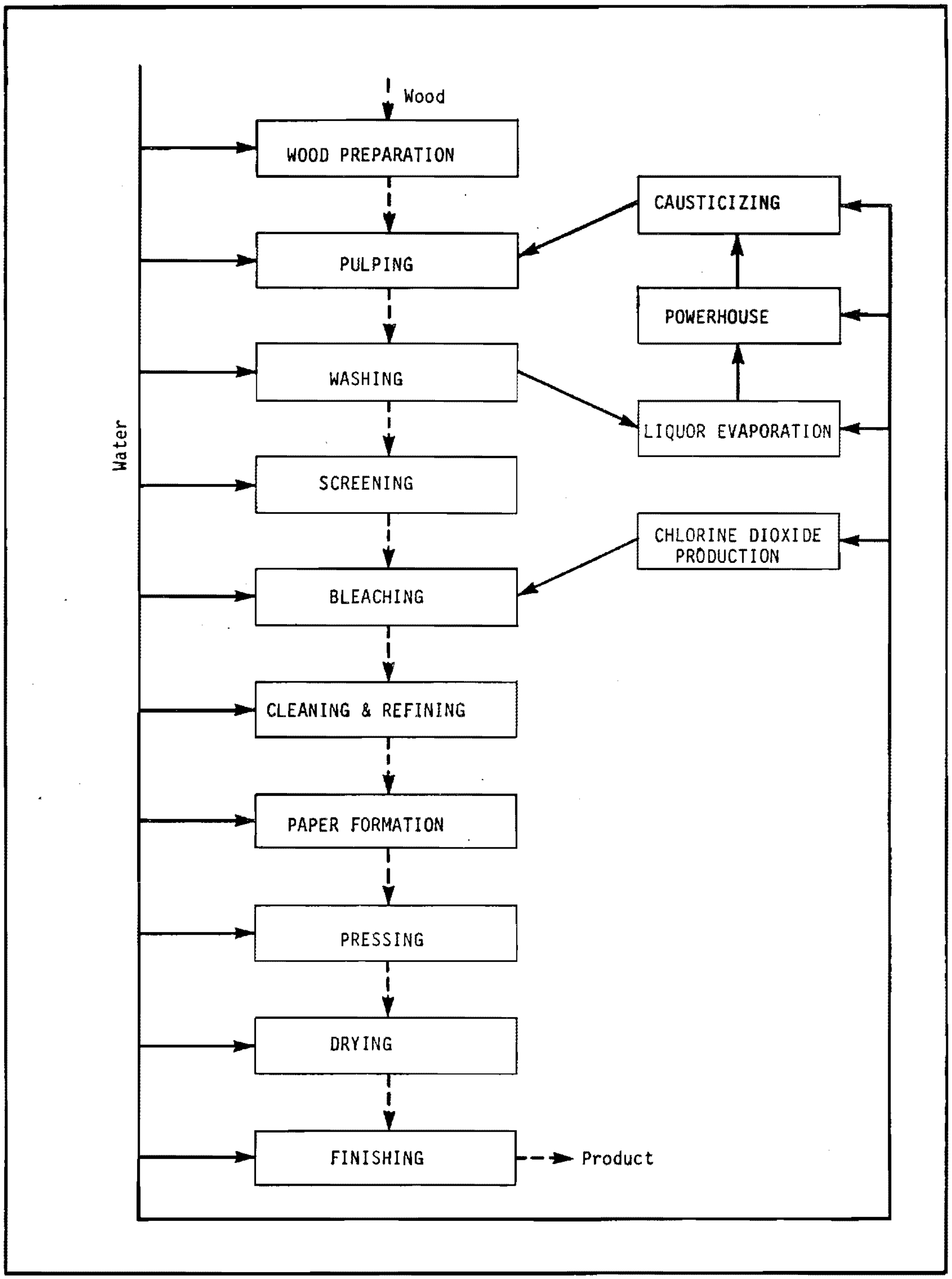


Figure III-31. PROCESS FLOW DIAGRAM FOR BCT BLEACHED KRAFT of their total product mix. As such, water demand differs significantly from mill to mill depending on the product quality mix produced. Table III-4 shows the typical water demands for this category.

Alkaline Fine - Figure III-32 shows the typical process "train" representing alkaline fine bleached Kraft operations. While mills in this category are similar to the BCT bleached Kraft mills, there is a significant difference in the degree of pulp refining required and in the pulp brightness sought from the bleaching operation. As a result of these differences, total water demand is typically higher than for the BCT category. Table III-5 shows the typical water demands for alkaline fine bleached Kraft.

Unbleached Kraft - Figure III-33 shows the typical process "train" representing the unbleached Kraft operation. This category includes the production of two basic grades of Kraft paper product: linerboards and bag/other mixed products. Processing requirements do not vary significantly from BCT bleached Kraft except for the absence of a bleaching stage. Table III-6 shows the typical water demands for this category.

Unbleached Kraft and Semi-Chemical - Figure III-34 presents the typical process "train" for unbleached Kraft and semi-chemical operations. This unique category of miscellaneous mill was given separate recognition because of the complementary potential of the two pulping operations. Typically the spent liquor from the semi-chemical process serves as a source of sodium and sulfur compounds found in the salt cake used in Kraft chemical recovery. Further, the "green" liquor produced after the Kraft recovery furnace has proven a suitable stream for use in making up the liquor charge used in the semi-chemical digestion of wood chips. Because of this unique combination, water demand is typically lower than would occur if each was performed separately. Table III-7 shows the typical water demands for this category.

Dissolving Sulfite Pulp - Figure III-35 presents the typical process "train" for the dissolving sulfite pulp operation. Because of the high product quality restrictions placed on this operation (i.e., a virtual absence of lignin, carbohydrates, and wood sugars), washing, cleaning, and bleaching processes must be very thorough, typically requiring large amounts of freshwater. The sulfite pulping process itself, as mentioned earlier, does not typically incorporate liquor recovery, thereby further increasing water demands for the continuous production of liquor. As in the case of dissolving bleached Kraft mills, production facilities making dissolving sulfite pulp typically do not process it further. This situation reduces somewhat the water demanded because many

Table III-4. BCT BLEACHED KRAFT STATISTICS

Number of mills	10
Total production	9,190 tpd
Total water	329 mgd
Average water	37,600 gallons/ton

Table III-5. ALKALINE FINE STATISTICS

Number of mills	20
Total production	13,100 tpd
Total water	588 mgd
Average water	44,900 gallons/ton

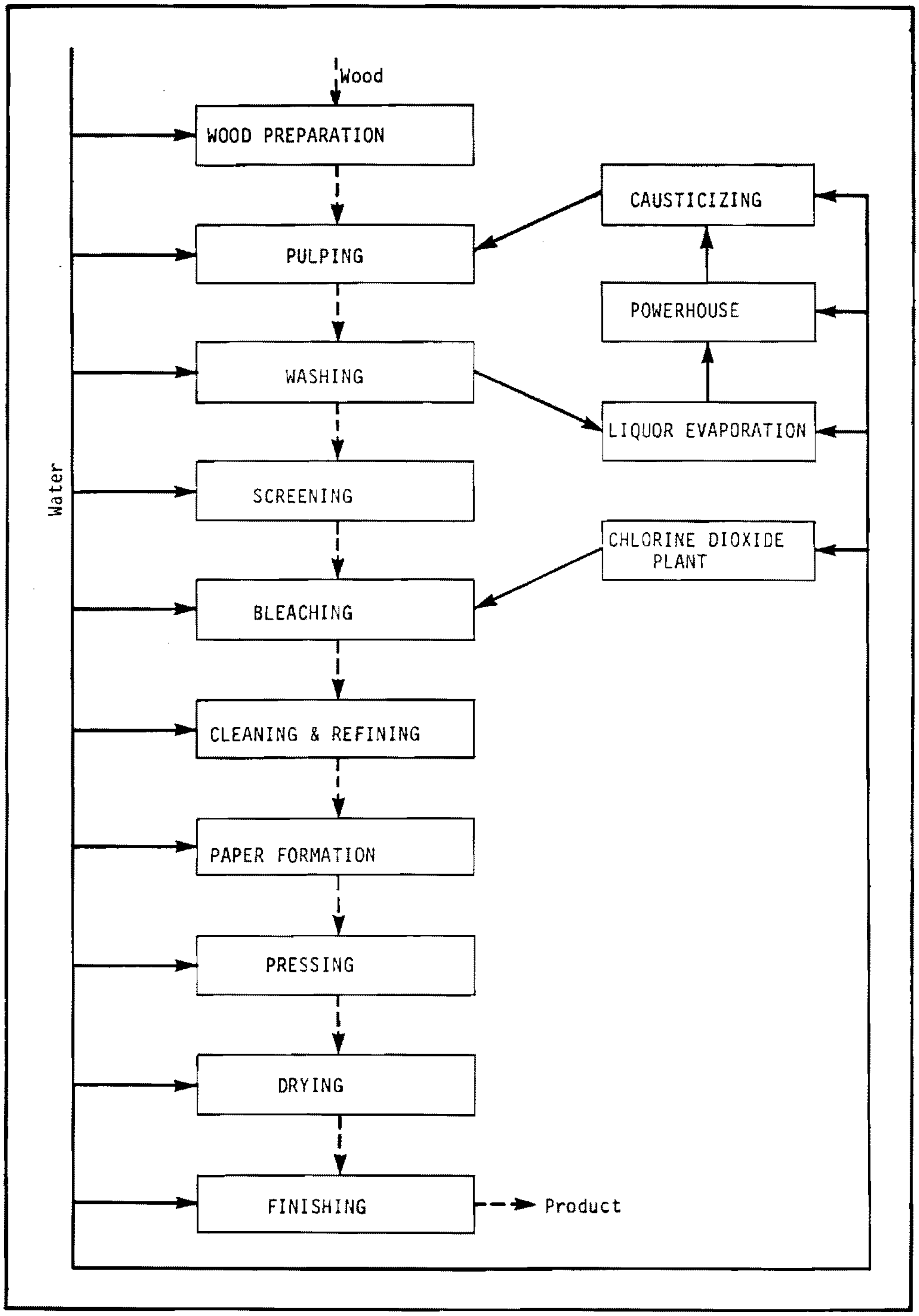


Figure III-32. PROCESS FLOW DIAGRAM FOR ALKALINE FINE

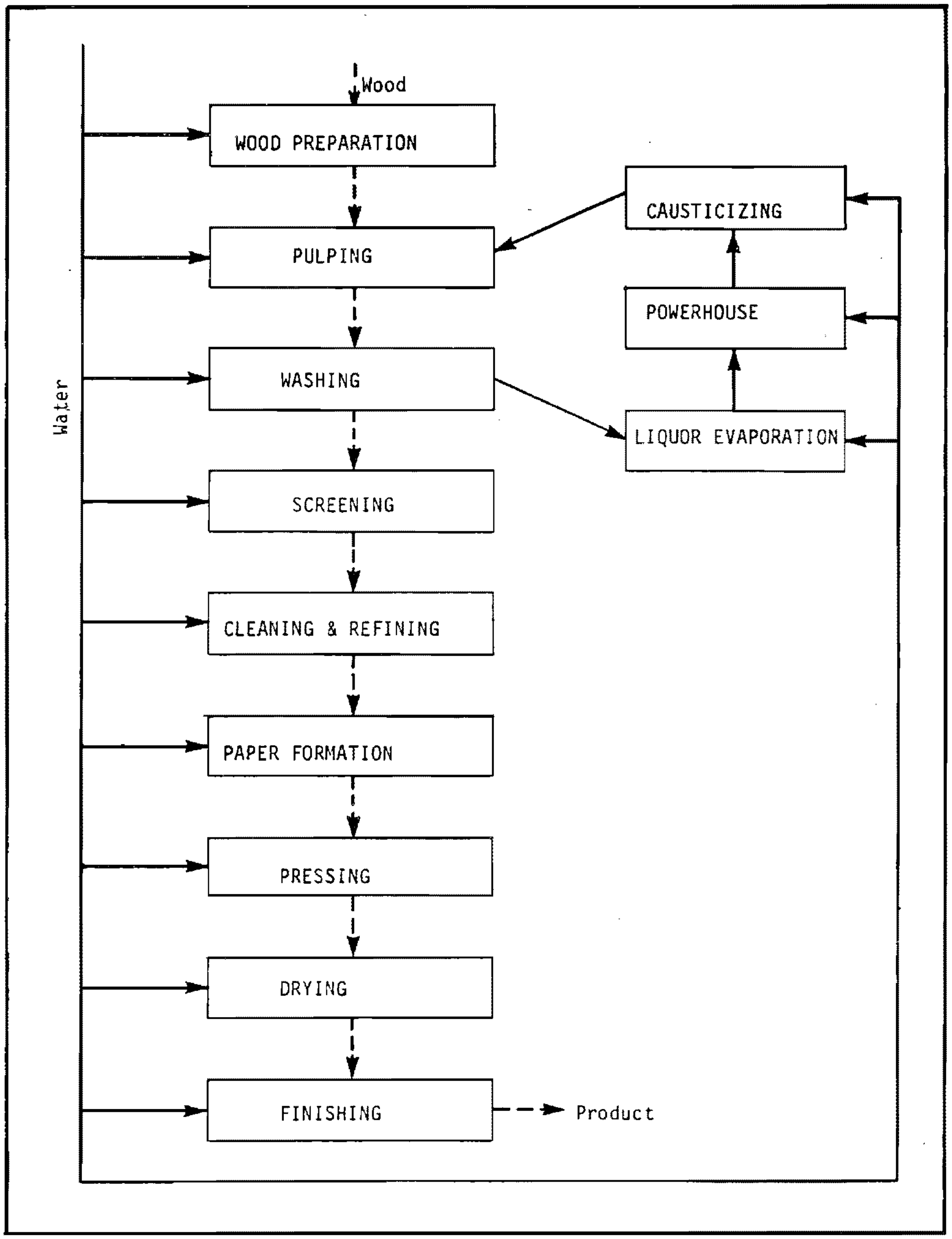


Figure III-33. PROCESS FLOW DIAGRAM FOR UNBLEACHED KRAFT

Table III-6. UNBLEACHED KRAFT STATIISTICS

Number of mills	28
Total production	30,492 tpd
Total water	480 mgd
Average water	15,800 gallons/ton

Table III-7. UNBLEACHED KRAFT AND SEMI-CHEMICAL STATISTICS

Number of mills	8
Total production	13,504 tpd
Total water	154 mgd
Average water	11,400 gallons/ton

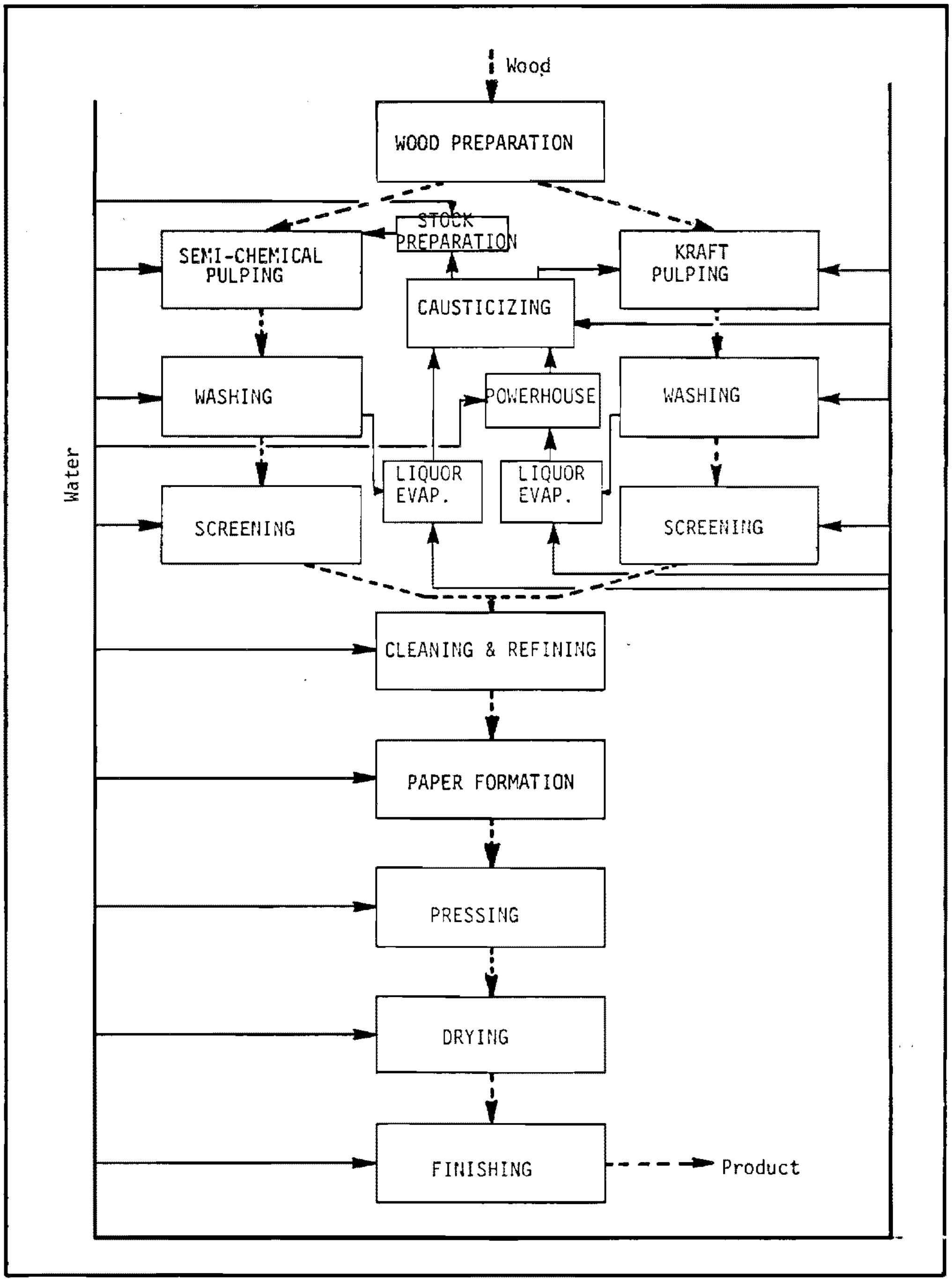


Figure III-34. PROCESS FLOW DIAGRAM FOR UNBLEACHED KRAFT & SEMI-CHEMICAL

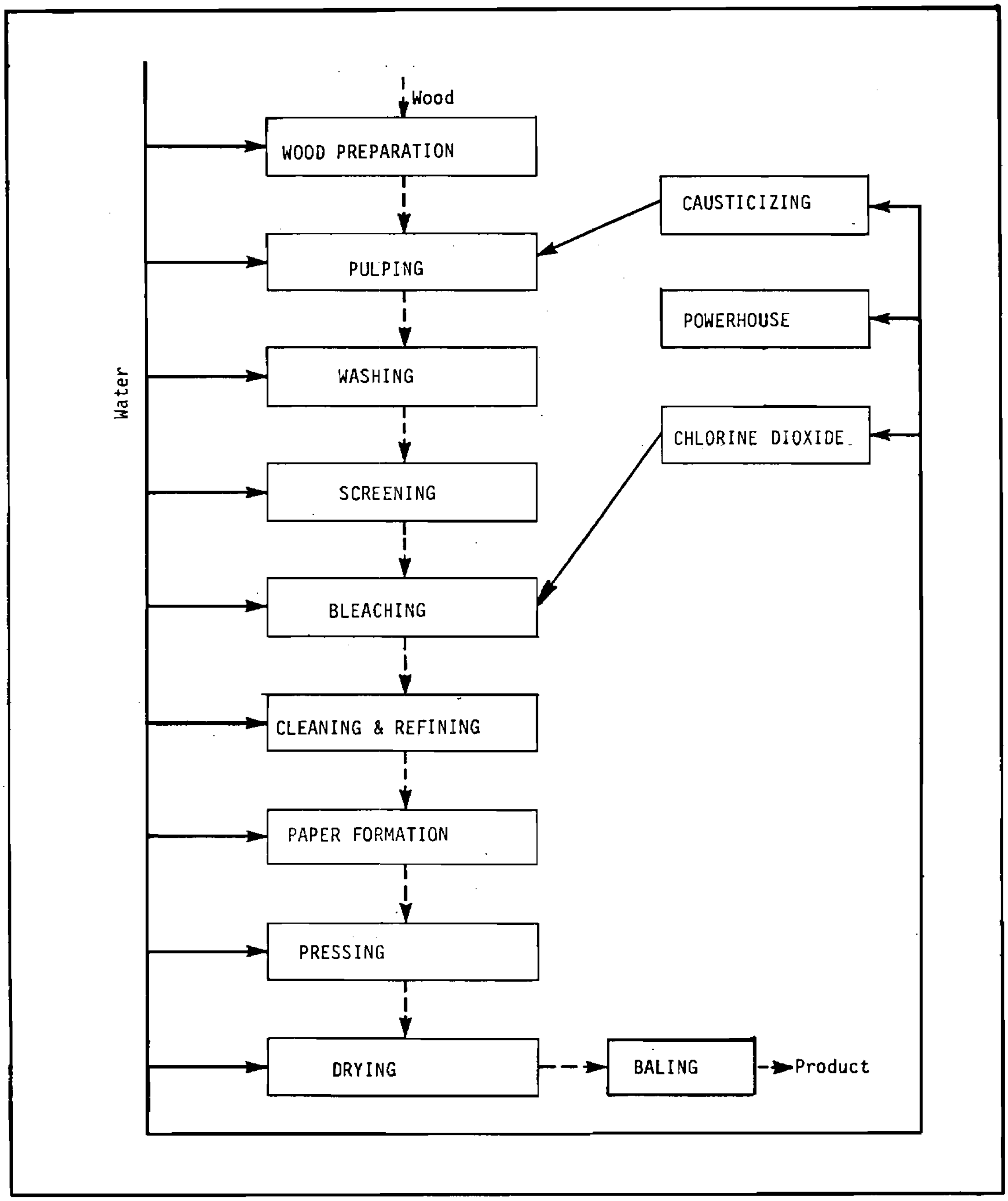


Figure III-35. PROCESS FLOW DIAGRAM FOR DISSOLVING SULFITE PULP finishing functions are absent. Table III-8 shows the typical water demands for this category.

Papergrade Sulfite - Figure III-36 presents the typical process "train" for the papergrade sulfite operation. Covering all grades of sulfite paper production together with mills producing market pulp as part of their product mix, this category closely resembles its Kraft counterpart with the exception of the pulp production and chemical recovery areas. Here again, the potential for water reduction through liquor recovery is not commonly practiced. Table III-9 shows the characteristic water demands for this category.

Integrated Miscellaneous Mills - No typical process "train" exists for this miscellaneous category because of the wide latitude possible in selecting pulp processing combinations. Such mills usually employ some combination of Kraft, sulfite, groundwood, semi-chemical, and chemi-mechanical pulping which greatly influence the potential for reuse/recycle. It is anticipated, however, that the evaluations of the separate pulping groups, as discussed in other subcategories, will provide comprehensive coverage of the range of major reuse options that exist for this group. Table III-10 shows the typical water demands for this category.

Nonintegrated Fine Papers - Figure III-37 presents the typical process "train" for nonintegrated fine papers operations. This particular group does not produce pulp but rather purchases market pulp which in turn is converted into fine papers. Because no pulp mill exists in these operations, many avenues of recycle/reuse outside of the paper area also do not exist. Table III-11 shows the typical water demands for this category.

PROCESS COMPUTER MODELING

Model Selection

The acquisition or development of a computer model capable of quickly calculating the impact of reuse/recycle options on the overall production process was given priority from the beginning of this study. Cost and applicability were the primary considerations in the model selection process. Of these two, cost was the most important since funds were limited for either licensing a commercial software system or for developing extensive new software. Applicability, however, also played a major role because the model had to be able to work with the data in hand and to provide values on key variables crucial to water-related process problems. A final decision was reached to use GEMS (General Energy and Material Balance System), a computer simulation model developed by Dr. L.L. Edwards at the University of Idaho.

Table III-8. DISSOLVING SULFITE PULP STATISTICS

Number of mills	3
Total production	1,550 tpd
Total water	110 mgd
Average water	70,600 gallons/ton

Table III-9. PAPERGRADE SULFITE STATISTICS

Number of mills	15
Total production	4,309 tpd
Total water	221 mgd
Average water	51,400 gallons/ton

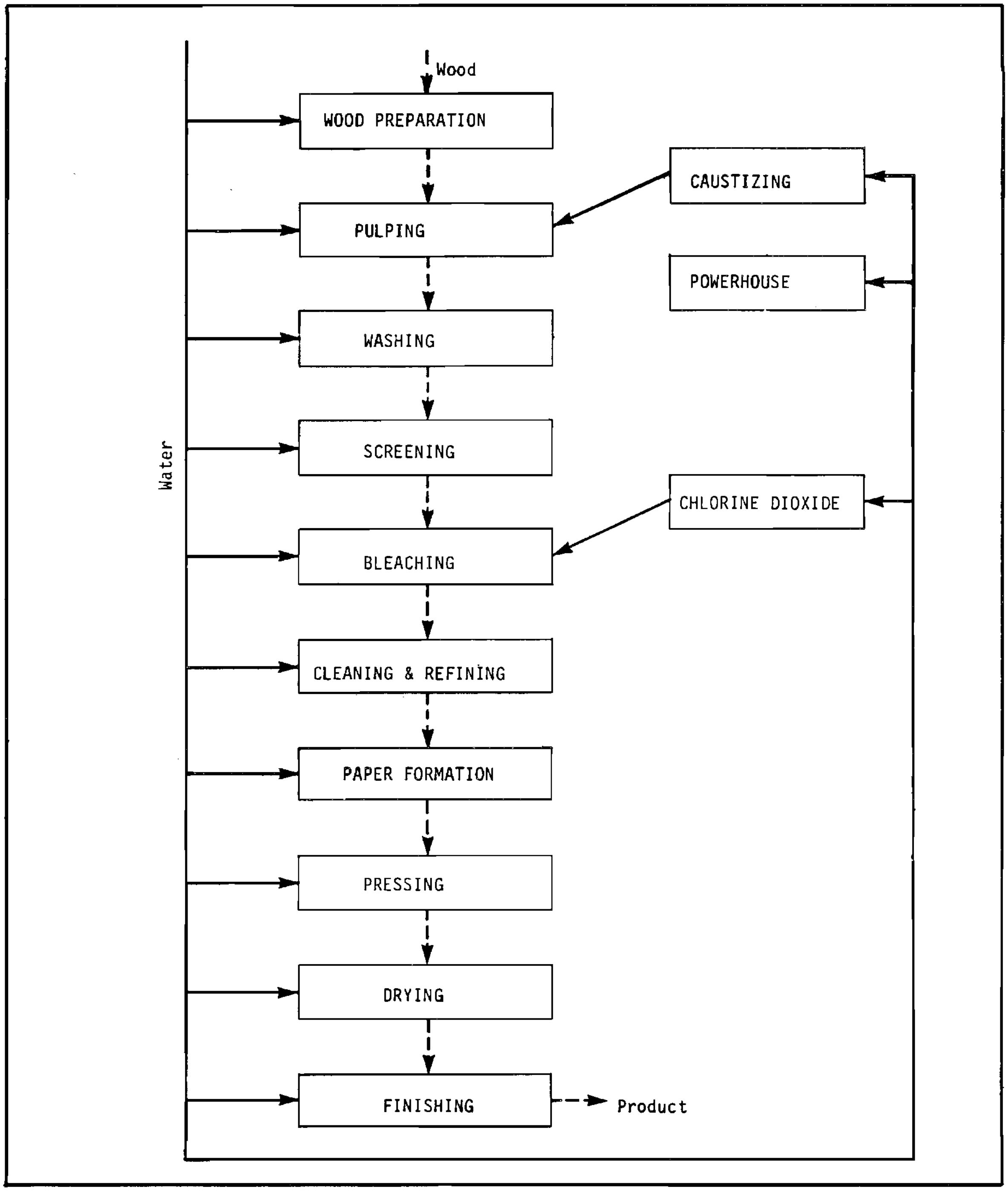


Figure III-36. PROCESS FLOW DIAGRAM FOR PAPERGRADE SULFITE

Table III-10. INTEGRATED MISCELLANEOUS STATISTICS

Number of mills	59
Total production	64,440 tpd
Total water	1,779mgd
Average water	27,600 gallons/ton

Table III-11. NONINTERGRATED FINE PAPER STATISTICS

Number of mills	42
Total production	4,478 tpd
Total water	141 mgd
Average water	18,800 gallons/ton

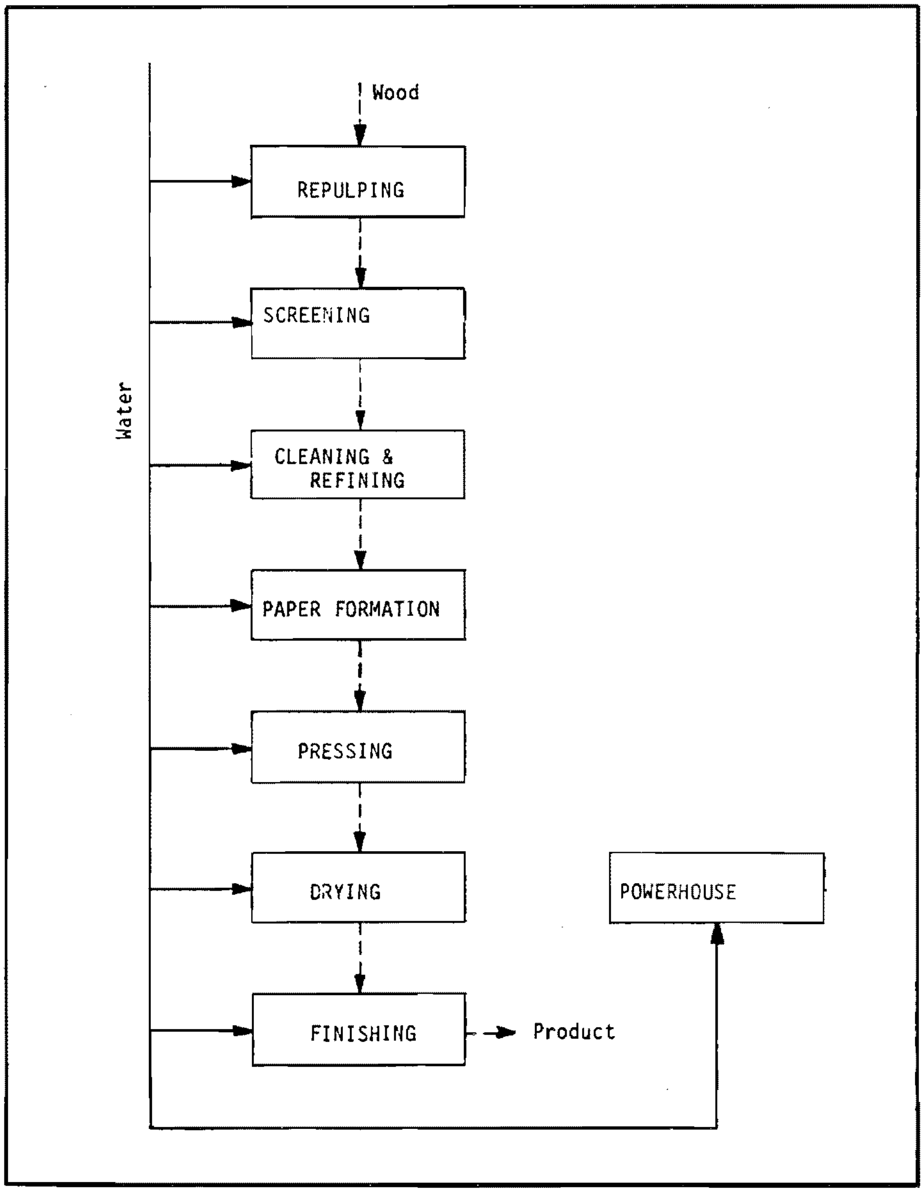


Figure III-37. PROCESS FLOW DIAGRAM FOR NON-INTEGRATED FINE PAPERS

GEMS is the most widely utilized computer simulation model in the pulp and paper industry. GEMS consists of an executive program and a set of generalized blocks representing each of the basic processing steps in a pulp and paper mill. In practice the engineer connects subroutines in a way that represents the mill flow sheet being studied and provides the executive program input flow rates, chemical charges, and other information. The sequence and method of calculations are identical to hand calculations, but much faster. When the steady state calculation is complete, liquor flow rates, pulp consistencies, pulp composition (e.g., long fiber fraction and fines fraction), chemical compositions, and temperature for all process streams are provided.[4] A general discussion of the program is included in Appendix C. Figure III-38 displays the functional stocks used by the model to simulate a bleached Kraft mill with the study subprocess "train" superimposed. The program was made available to the study at no cost through a special arrangement with Dr. Edwards.

Three other major software systems are also available for use by in study:

- o FLOWTRAN, available from the Monsanto Company
- o ASPEN, available from the Massachusetts Institue of Technology
- o DYSCO, available from the Institute of Paper Chemistry

FLOWTRAN and ASPEN are state-of-the-art for simulation in the chemical industry, but were not developed for the peculiarities of pulp and paper application as were DYSCO and GEMS. FLOWTRAN and ASPEN do not model equipment directly used in the industry as do GEMS and DYSCO. GEMS and DYSCO are both modular systems using iterative solutions to material and energy balances and are both very suitable for running alternate flow patterns within a mill.[9] GEMS, however, has the major advantage over DYSCO of being the most widely accepted software system in the paper industry.

The strengths and weaknesses of GEMS from a user's point of view are many and varied. Listed below are a few of the more significant:

<u>Strengths</u>

- o One of GEMS' major strengths is its programming structure. Using the executive program to control various process subroutines, this structure allows the user to change the process to be modeled by only switching the order in which subroutines are called. This eliminates the need to completely recode changes. Many alternatives can be patterned in such a structure:
  - o Flows can be rechanneled, such as in a recycle loop..
  - o Equipment and stream parameters can be changed by simply changing subroutine arguments.
  - o Entire sections of the mill can be added or deleted by the construction of super blocks.

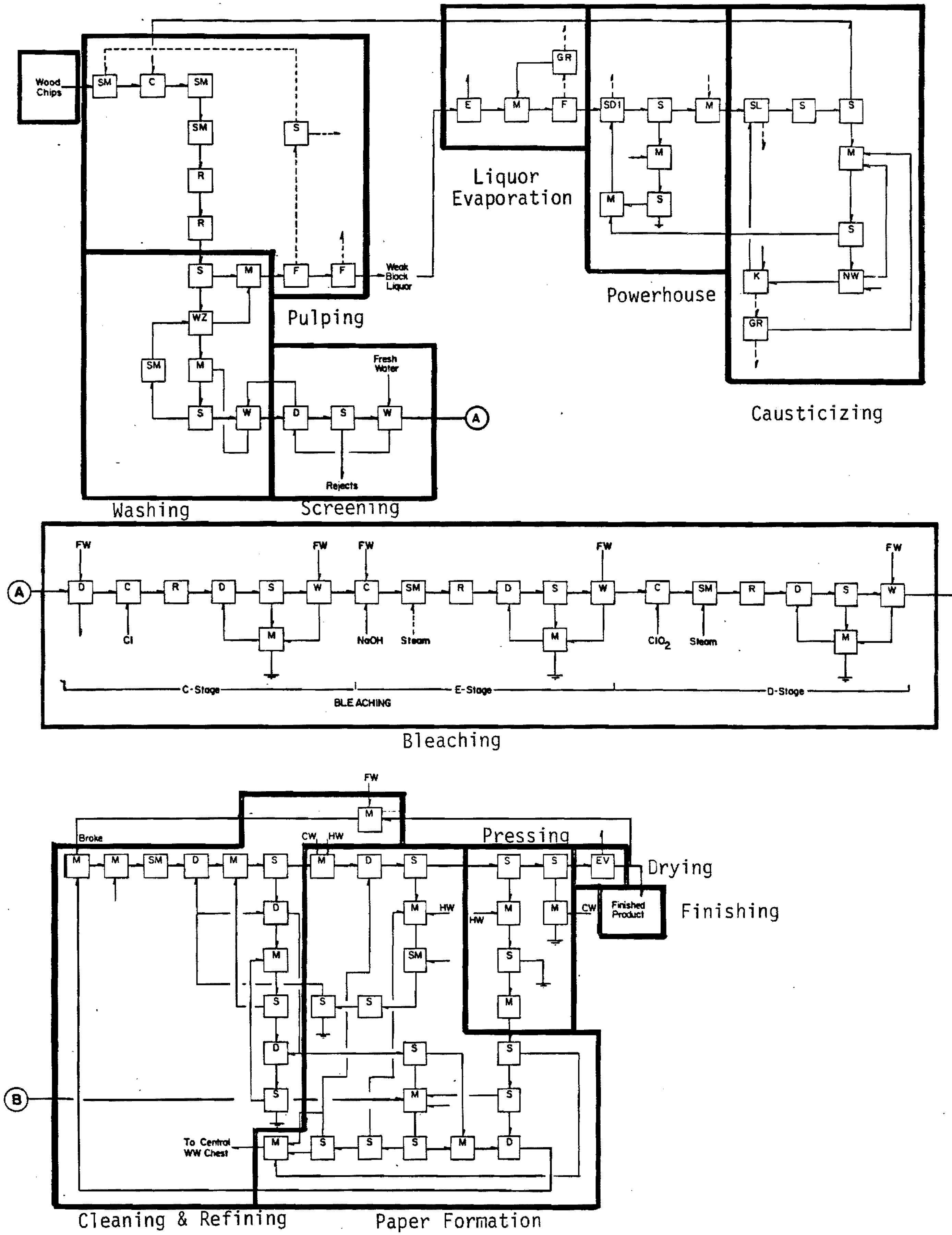


Figure III-38. GEMS PROCESS BLOCKS WITH CORRESPONDING PRODUCTION PROCESS ACTIVITIES

This structure also lends itself to isolating problem points in the process by having errors reported specifically for a given block, not from an error report on the entire program. Information is also provided for individual blocks allowing careful examination of violations of physical constraints such as steam temperatures and solids buildup. GEMS possesses the ability to run several different equipment and stream parameter permutations in a single batch submission. GEMS possesses the ability to track various stream components through a given process. Up to 14 variables may be tracked on a given run, with certain chemical species manipulated specially as warranted by the process (i.e., $CaCO_3$ in the recausticizing area). Details regarding the components tracked may be determined easily even to the point of tracing various wood fractions through the process.

- The GEMS input format is simple but rigid. The user specifies which subroutine he/she desires to use, the order to be called, the number of streams in the process, and all equipment and input stream parameters. While the amount of data required is extensive, many bits of information can be obtained from textbooks or derived from easily obtained data.

- A number of publications exist in which GEMS has been used to analyze pulp and paper processes. Of particular interest to this study were applications developed for other purposes but adaptable to this project. Documented runs were found to exist for essentially all parts of a typical Kraft mill including the pulping section, chemical recovery, bleaching, and pulp drying. This proved useful in speeding the selection and verification of inputs needed to properly model the existing industry. Work therefore could focus on modifying input parameters from published sources to the specifications found to be prevalent in the industry.

Weaknesses

- Major weaknesses for GEMS were found in the software with the most serious being in the simulation outputs. Even the most trivial changes in equipment or stream parameters required a completely new execution of the program, and the output received was in the same long, detailed format of an entirely new simulation. The result of this limitation was a great deal of excess computer execution time and printing for minor input adjustments.

- GEMS, as designed, operates only on metric units. While this is appropriate in light of national efforts to so standardize, the fact that the industry still largely uses English units requires constant conversion back and forth between the two. Until metric units are more widely accepted by the industry, an option to utilize English units would greatly facilitate simulation runs.

Model Adjustments

After obtaining the GEMS program, considerable work was necessary before recycle investigation runs could be made. This work centered on two closely related activities:

- o Adjusting the variable model parameters to simulate observed pulp and paper process conditions.
- o Defining the baseline at which refinement runs should begin.

In selecting representative model parameters, efforts were first focused on analyzing the various assumptions made in published simulations,[4,6,8] checking all input data, and rearranging process flows as needed. Analyses were confined to modifying published GEMS flow patterns rather than constructing new patterns from scratch. This allowed a rapid development of representative conditions even though significant modifications to flow patterns were made.

Defining baseline conditions for runs consisted of checking model output flow parameters for agreement with what is considered normal or average within the industry. Data for these parameters came chiefly from the literature, with some input obtained from the mill visits. This activity provided the greatest impetus for modification because many of the original flows produced results which were found to be in gross disagreement with published data. Verification was performed for four basic areas of the paper process.

1. Pulping
2. Pulp drying
3. Bleaching
4. Chemical recovery

The pulping section required the least amount of modification. Of primary concern was the gross flow pattern which included the stock input flow and its moisture content, wash water flow, and brown stock flow from the last decker. All flows were scaled to reflect an input for a 1400 tpd mill. The principal water flow in the section, indeed the largest in the mill, was the decker wash water. Rather than modeling three individual washers separately as is characteristic in a mill, all washing manipulation was performed in a single wash block. The digester modeled was a continuous design and was composed of six functional blocks: two steam-mix blocks, followed by two react blocks, a split block, and a wash zone block. The steam-mix blocks model the indirect heating used to increase stock temperature from ambient to a cooking temperature of 170°C. The react blocks model the chemical reactions converting the pulp into a slurry, and those that the white liquor undergoes during cooking. A split block inserted after the two react blocks acts to vent off the temperatures. Last in the digester model is a wash zone block used to model the wash section in the bottom of a typical digester. The most significant change made in the original pulping model was the addition of the capacity to individually track the wood slurry and wood fines produced during cooking. Fines were tracked throughout the rest of the model and served as an important water quality constraint. Decker wash water temperatures were increased to 95°C to reflect the recycle of evaporator condensate rather than 40°C mill service water. This adjustment proved a major constraint to further water recycle because of its subsequent effect onpaper machine temperatures.

By far the largest amount of modification came in the pulp drying area. The setup originally selected as a basis for modeling was a published design for dynamic simulation of combination newsprint and Kraft, recycled broke paper process. Modifications were made to change this to a steady state simulation of a typical Kraft mill. Changes centered around three areas:

1. Gross input/output stream flows
2. Machine and stream temperatures
3. Changes in the process flow sheet

The major stream flows examined were the brown stock feed, gross white water, vaccuum pump seal water, and felt shower conditioning water. Verification centered around using the input flows considered industry standards and subsequently balancing those flows internally to produce the correct output stream flows. Such effort required tedious adjustment of internal streams to reproduce both accurate external flows and to preserve internal flow accuracy. Adjusting the pulp drying temperatures required accurate data on all input stream temperatures, along with knowledge of the effect and purpose of any heat transfer equipment in the process. This adaptation of the model proved more involved than expected. The machine originally modeled contained assumptions of lower temperature water characteristics typical for a northern based mill. Machine temperature was fixed at about 120°F. This temperature was increased to levels more characteristic of the industry as a whole by two modifications:

1. Wash water temperature was increased to 200°F.
2. Mill service water temperature was increased from 45°F to 77°F.

These changes produced a new machine temperature of 140°F.

Several changes were made in the flow sheet to reflect a more typical flow pattern. Kraft pulp was changed to feed into the machine chest rather than the saveall as originally designed. A "sweetener" stream of 1% of the pulp coming from the machine chest was routed to the saveall to insure that the vacuum on the saveall driers was maintained.

Various other adjustments were made to the model as needed. Stream consistencies were lowered slightly across the fourdrinier to about 0.4% to reflect data gathered. Steam consumption in certain areas of the mill was eliminated as temperatures across the machine were increased. Water flow rates and input composition were changed from pure water to that reflecting mill service water, i.e., dissolved solids content, sulfides, carbonates, and other chemical components were included.

A simple bleach plant was modeled based on a design found in the literature. Separate investigations were later performed on both bleached and unbleached mills. The bleached mill was modeled by simply adding a bleach plant to the unbleached mill model. Blocks used in modeling the bleach plant were combined into one large block.

The bleach plant modeled[7,8] is a five-stage process, each stage requiring different chemical inputs. The stages are arranged in the following sequence based on chemical input:

- Chlorine
- Extraction
- Dichloride
- Extraction
- Dichloride

The bleach plant section involves essentially five repetitions of the same stage, with adjustments made for the proper chemical charges, and any temperature controls needed for a particular stage reaction. Each stage is made up of five basic blocks. The pulp from the prior stage is introduced into the next stage through a charge block which adds the proper amount of chemical specified for a given chemical reaction. Pulp and chemicals are then transferred into a react block in which stream variables are manipulated by the reactions taking place. In an actual mill, these two functions are performed in a single retention vessel. From this point, pulp flow moves into a washing substage. This is modeled by a wash block, followed by dilute and split blocks which set flows of recycled water, and output pulp at the proper consistency and composition. The analog to this model in a mill is a standard decker.

Results from simulation runs made on the adjusted overall model showed it to be an accurate representation of typical pulp and paper systems. Total mill water consumption in these runs equalled a value accepted as a median for the industry. Temperatures and stream compositions when computed also compared favorably to data from the industry.

References - Section III

1. Brett, Kenneth W., "Handbook of Pulp and Papers Technology," Reinhold Publishing Co., New York, 1964.

2. U.S. Environmental Protection Agency, "Development Document for Proposed Effluent Limitations Guidelines and Standards for the Pulp, Paper, and Paperboard and the Builders' Paper and Board Mills Point Source Categories", U.S. Government Printing Office, Washington, D.C., 1981.

3. Rydholm, Sven A., "Pulping Processes", John Wiley & Sons, New York, 1965.

4. Edwards, Lou and Balders, Ron, "GEMS: Documentation Describing Data Input, Simulation Control and Simulation Options", Chemical Engineering Department, University of Idaho, Moscow Idaho, 1979.

5. Edwards, Lou and Balders, Ron, "GEMS: Documentation Describing Process Subroutines". See #4 above for source information.

6. Venkatesh,V.; Kirkman, A.; Mera, F.; "Computer Aided Process Analysis and Economics for Pulp and Paper Mills" TAPPI, March, Vol. 61 (3), 1978 (p. 87).

7. Brown, Glendon W., "Computer Simulations of Paper-making to Evaluate Water Reuse Strategies", Tappi Papermakers Conference, Preprints Atlanta, GA, April 26-29, 1976, p. 93-101.

8. Gunseor, F.D. and Rushton, J.D., "Computer Simulation of a Bleached Kraft Pulp and Paperboard Mill", TAPPI, 62 (3), 1979 (p.63)

9. Newcombe, Julie A.; Dysco, "Dynamic Simulation and Control", Institute of Paper Chemists, 1981.

10. Metcalf & Eddy, Inc., "Wastewater Engineering: Treatment/Disposal/ Reuse", 2nd Edition, McGraw-Hill Book Company, New York, 1979.

Section IV

EVALUATION OF CURRENT EFFORTS TO RECYCLE/REUSE WATER

INTRODUCTION

The freshwater requirements for the ten production categories examined in this study has steadily been decreasing in recent years. Industry wide data for all mill categories has shown a reduction from an average of 39,000 gal/ton in 1955 to about 27,000 gal/ton in 1972.[1] Table IV-1 shows current freshwater usage rates for the various paper/pulp sectors. Reductions of this magnitude have continued into the 1980's as environmental regulations and energy costs have motivated the industry to continue their increase in water recycle.[2] By the year 2000 the nation will require an anticipated one trillion gallons of water per day.[3] Even though the pulp and paper industry will require a significant portion, average mill recycle rates will probably exceed 1000%, well above the present level of about 290%.[4]

The force of environmental regulation coupled with the more historic economic incentives to conserve chemicals, energy, and fiber has led to significant levels of capital being invested to reuse/recycle water.[2] Studies conducted in the early and mid-70's showed only a partial picture of this trend to reuse/recycle because many programs were just beginning.[5] However, the results of this progress are clearly evident today as widespread development, commercialization, and operation of improved reuse schemes are seen throughout the industry.

This section discusses the extent of current water usage in the pulp and paper industry, focusing on both common place and emerging reuse/recycle schemes. Also, a discussion of the many constraints to further growth is included. Data used in this presentation obtained from published sources was found to be very limited. Therefore, a series of mill visits were scheduled during this study to collect specific operating data from 25 operating facilities. The findings from these visits are discussed throughout this section with a summary of the survey effort itself presented in detail in Appendix C.

OVERVIEW OF CURRENT WATER USAGE PATTERNS

Table IV-2 compares the present industry averages for freshwater consumption with those mills that operate at exceptionally low consumption levels (using what many consider the best technology available today). From conversations with various mill officials, closing the gap between "best available technology" and present averages has proceeded at an extremely slow rate for the past two to three years. The reasons for this slowdown in activity are quite

Table IV-1. TOTAL WATER USAGE BY PULP AND PAPER PROCESS CATEGORY

Mill Category	Kgal/d
Dissolving Kraft	159,125
Market Bleached Kraft	206,820
BCT Bleached Kraft	250,848
Alkaline Fine	390,788
Unbleached Kraft	449,929
Semi-Chemical	56,240
Unbleached Kraft & Semi-Chemical	195,968
Dissolving Sulfite Pulp	211,118
Papergrade Sulfite	260,678
Groundwood Thermo-Mechanical	13,496
Groundwood CMN Papers	50,582
Groundwood Fine Papers	58,909
Integrated Miscellaneous Mills	1,490,720
Deinking Fine Paper	24,265
Tissue from Wastepaper Industrial Tissue	2,953
Sanitary Tissue	6,480
Paper from Wastepaper	84,621
Wastepaper Molded Products	10,824
Builders' Paper and Roofing Felt	10,032
Secondary Fibers Miscellaneous	36,660
Nonintegrated Fine Papers	170,494
Nonintegrated Tissue Papers	67,361
Nonintegrated Lightweight Papers	51,177
Nonintegrated Filter & Nonwoven Papers	2,229
Nonintegrated Paperboard	14,746
Nonintegrated Miscellaneous	36,278
Total	4,162,766

Table IV-2. COMPARISON OF AVERAGE WATER USAGE VERSUS THE LOWEST WATER USERS OF THE 10 SUBCATEGORIES STUDIED

	1981 AVERAGE WATER USAGE (gallons/ton)	1981 LOWEST WATER USAGE (gallons/ton)
Dissolving Kraft	44,200	34,500
Market Bleached Kraft	35,000	17,000
BCT Bleached Kraft	37,600	24,800
Alkaline Fine Paper	44,900	19,500
Unbleached Kraft	15,800	5,600
Unbleached Kraft & S.C.	11,400	7,300
Dissolving Sulfite	70,600	66,700
Papergrade Sulfite	51,400	9,300
Miscellaneous Integrated	27,500	5,500
Non-integrated Fine Paper	18,400	5,600

varied. Below are listed some of the major factors which have been identified:

- o Weakening in regulatory pressures for continued reduction in effluent loads.
- o Reduced availability of capital for longer payout projects due to a soft product market.
- o Shift in emphasis to high payback energy projects.
- o Difficulty in quantifying the savings potential of increased reuse/recycle.

In the immediate future, water reuse/recycle levels are not expected to change significantly from those of today. The sluggishness of the pulp and paper market over the past few years appears to be the dominating factor influencing this behavior. However, as pulp/paper inventories drop, longer range capital spending programs should once again begin to flourish. If this happens it is likely that renewed expenditures will be made on water reuse/recycle projects.

Field studies during this research effort uncovered some interesting points regarding mills in certain production categories. The categories of dissolving sulfite and dissolving Kraft pulp displayed the lowest deviations in freshwater consumption from national averages. Efforts to reuse/recycle water by mills in these categories have apparently reached limitations which impede further reduction in freshwater consumption. As shown in Table IV-2, these two categories also represent significant consumers of freshwater per unit of production. Discussions of water reuse/recycle limitations with various mills in these categories identified the more significant problems of:

- o Final product quality
- o Control of machine white water quality
- o Limited economic incentive to reuse/recycle

It was further found that mills in these specific categories, were generally located on plentiful sources of high quality freshwater, which is a primary influencing factor affecting priorities for further reuse/recycle.

Bleached and unbleached Kraft mills as a class showed the greatest deviation from national averages. This is caused by the significant variations in product quality and freshwater resource availability. The Kraft process, it must be noted, is the dominant pulping technique utilized in this country, having been adapted to almost every region and wood type.

It is interesting that many mills with similar processes and products have widely varying approaches in water reuse/recycle. Outwardly it appears that a cost effective system arrangement for one mill would be attractive to another. The most notable example of this concept is in the utilization of evaporator clean condensates (see Figure IV-1). Most mills do not find this source of water suitable for reuse in

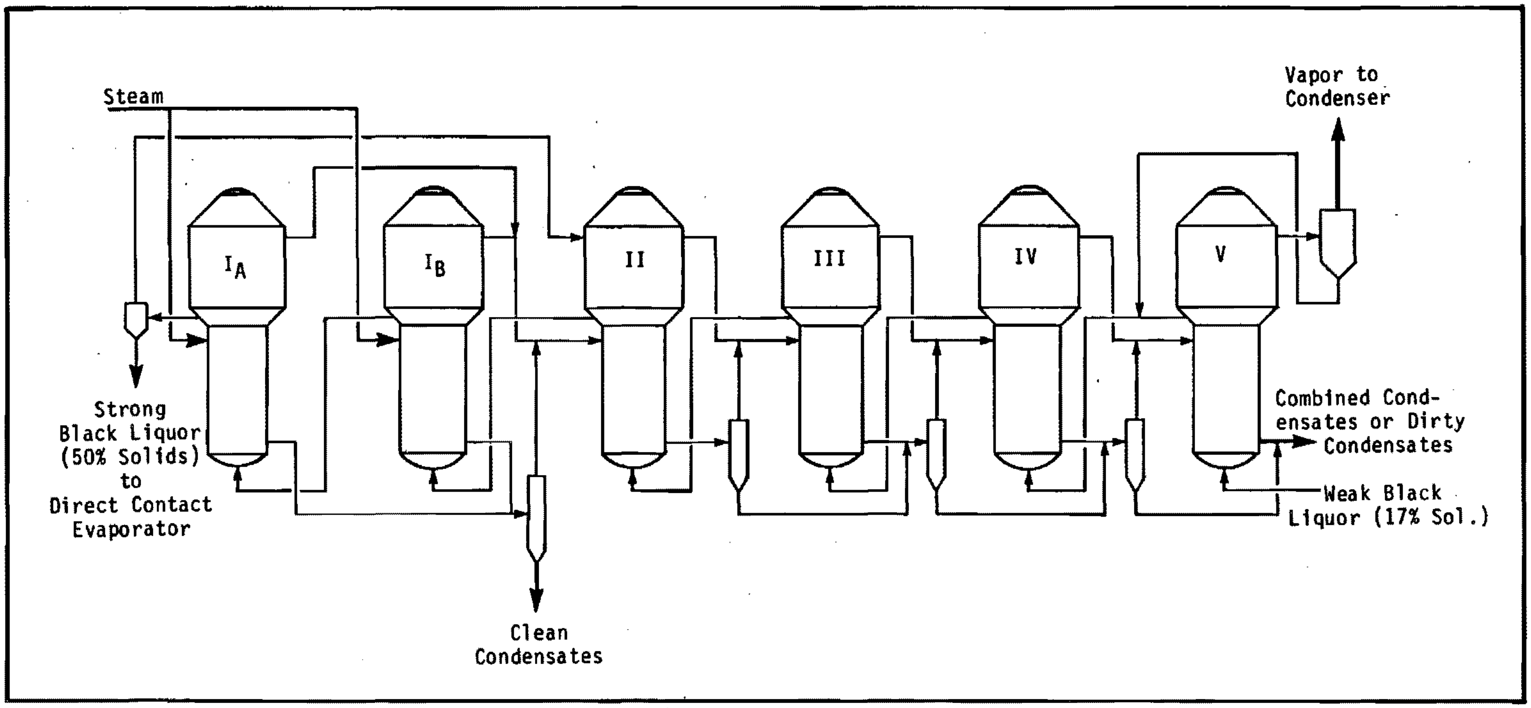


Figure IV-1. TYPICAL KRAFT 5 EFFECT BLACK LIQUOR EVAPORATOR ARRANGEMENT boiler feedwater. Because of a history of contamination or an occasional evaporator upset, mills typically will resort to applying this stream only to the pulping area for brown stock washing (see Figure IV-2). Yet, some mills have been able to control their processes well enough to allow them to confidently utilize this high quality source of water for feedwater make-up and even shower water in the bleach plant.

Recycled water should be applied where it can be of optimal benefit for its quality. A mill does not generate superheated, 800 psig steam for a heating application where 150 psig steam is called for, nor should it apply hot, demineralized condensate to areas where the high quality is not needed, such as in brown stock washing. The cascading concept of thermal energy applies equally well for water quality within a mill. A mill should incorporate a policy of using high quality water first in high quality applications and low quality water for low quality needs.[6]

It could be argued that this concept is overly simplistic in that it does not address the many technical problems that can occur, such as contaminant buildup in tightly closed processes. Problems such as corrosion, scaling, and thermal buildup often are associated with new water recycle/reuse schemes.[2] Yet solutions to these problems are prevalent in the literature, and many reuse/recycle schemes are working well in certain mills today despite such problems.

Recycle measures found in mills today can be illustrated using four fundamental pulp and paper process groups:

- Bleached Kraft
- Unbleached Kraft
- Bleached sulfite
- Nonintegrated paper

Figures IV-3, IV-4, IV-5, and IV-6 show subprocess wastewater recycle loops found in use today for these groups. These figures are accompanied by Tables IV-3, IV-4, IV-5, and IV-6 which define the indicated recycle loops. These figures and tables also identify major subprocesses for which freshwater requirements have been virtually eliminated in many plants through the substitution of wastewater streams.

Subprocess recycle is also extensively used in the industry. Here a fraction of wastewaters in a subprocess is simply rerouted back into the same subprocess to augment freshwater requirements. Below is a discussion of various approaches used by industry to control freshwater usage.

Woodyard operations, which include showers, sprays, woodflumes, and hot ponds but exclude applications such as cooling water for bearings and air compressors, today employ the use of wastewater in almost all phases of wood preparation. Replacing water intensive devices with dry or semi-wet devices further reduces water demand. In

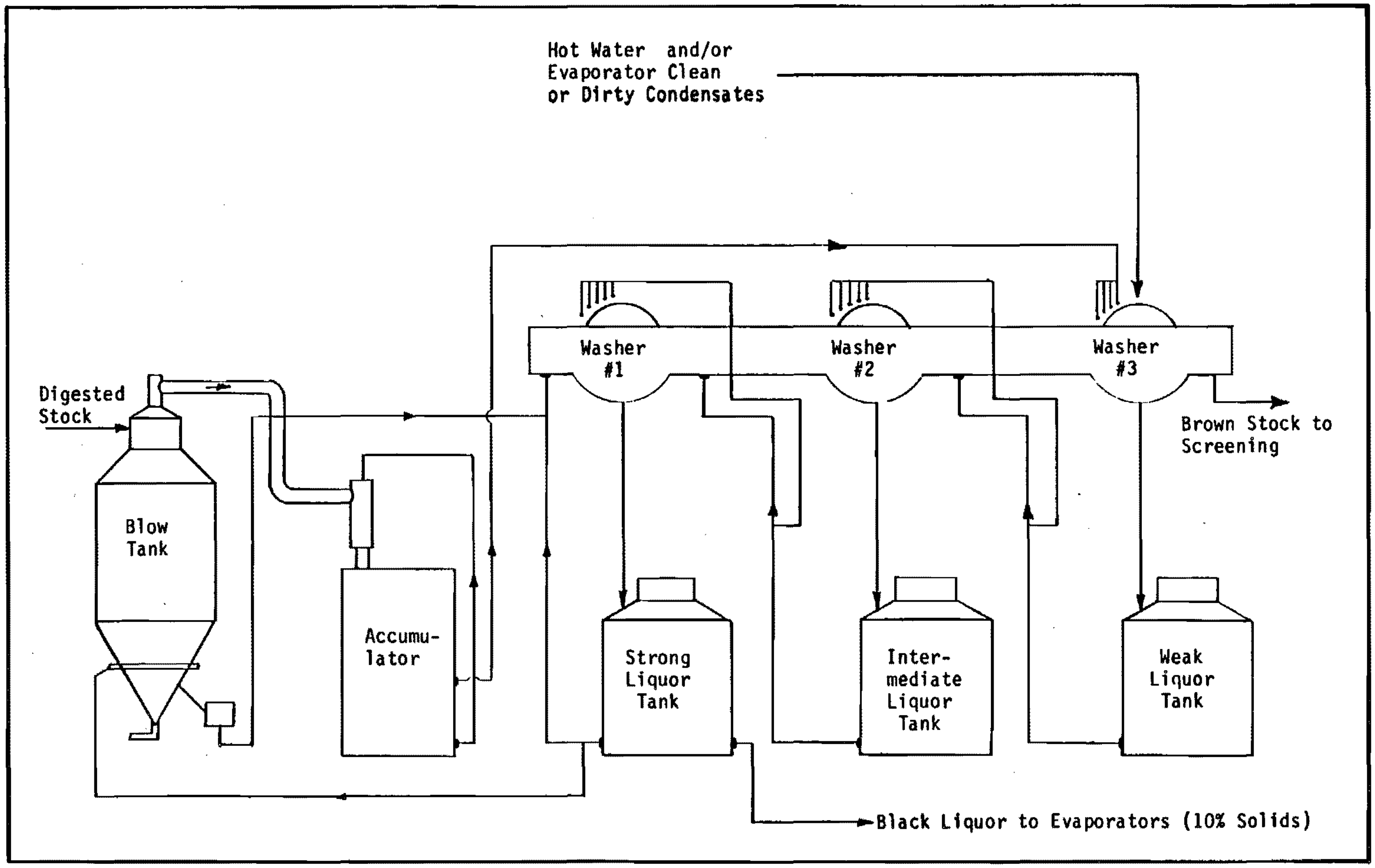


Figure IV-2. TYPICAL ALKALINE BROWN STOCK WASHING PROCESS FOR BATCH DIGESTION

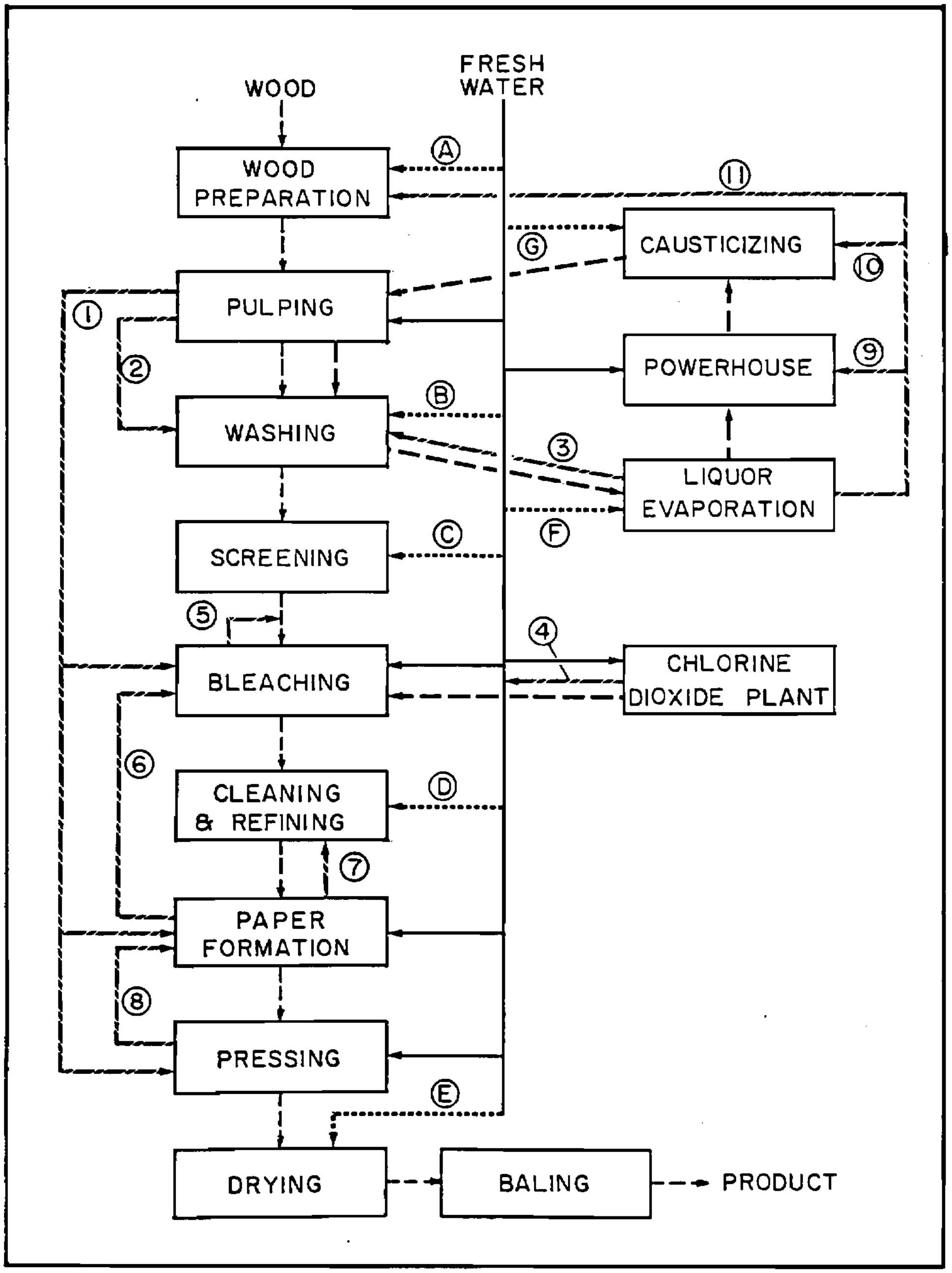


Figure IV-3. TYPICAL BLEACHED KRAFT PULPING PROCESS

Table IV-3. MARKET BLEACHED KRAFT WATER RECYCLING

TYPICAL RECYCLE LOOPS

1- Blow gas condenser cooling water is used as hot water source for bleach washing and machining showers (stock heating).

2- Turpentine decanter underflow is used for brown stock washers and knotter showers.

3- Liquor evaporator condensates are utilized for brown stock washing.

4- Chlorine dioxide plant cooling water is recycled to process fresh water supply.

5- Chlorination effluents are used for unbleached stock dilution.

6- Machine white water is utilized for final bleach stage shower and dilution water.

7- Machine white water is utilized for all dilution/shower water in stock preparation.

8- Press effluents are reused for machine white water make-up.

9- Liquor evaporator condensates are utilized for boiler feed water make-up (clean condensates), causticizing mud washers, lime kiln scrubbers, dreg washing, and wood yard requirements.

SUBPROCESSES WITH FRESH WATER USE PRACTICALLY ELIMINATED

A- Wood Preparation: All wood flumes utilize recycle waters. Wet debarking has typically been eliminated. Remaining water requirements are met with process wastewater.

B- Washing: Brown stock washing is typically accomplished entirely with wastewater from the evaporators and turpentine decanter underflow from pulping.

C- Screening: Stock screening is typically relocated immediately upstream of washing. Thus screening dilution comes from weak black liquor. If not, then stock screening retains its place in the process stream (after washing) with high levels of water recycle and water make-up from the decker filtrate. Decker filtrate shower water is principally supplied from evaporator condensates.

D- Cleaning/Refining: Stock preparation waters are met primarily with machine and/or press section white water.

E- Drying: Cooling water for drum bearing lubrication system, air conditioning, etc. is recycled via an evaporative cooler, or cooling water is returned to fresh water reserviors. Repulp of off grade stock may be met with machine white water.

F- Liquor Evaporation: Condenser cooling water is recycled via an evaporative cooler, or cooling water is returned to fresh water reservoirs. Repulp of off grade stock may be met with machine white water.

G- Causticizing: Water requirements for mud washing, dregs filter showers, and lime kiln scrubbers are supplied by other subprocess waste streams. Cooling water is returned to fresh water reservoirs.

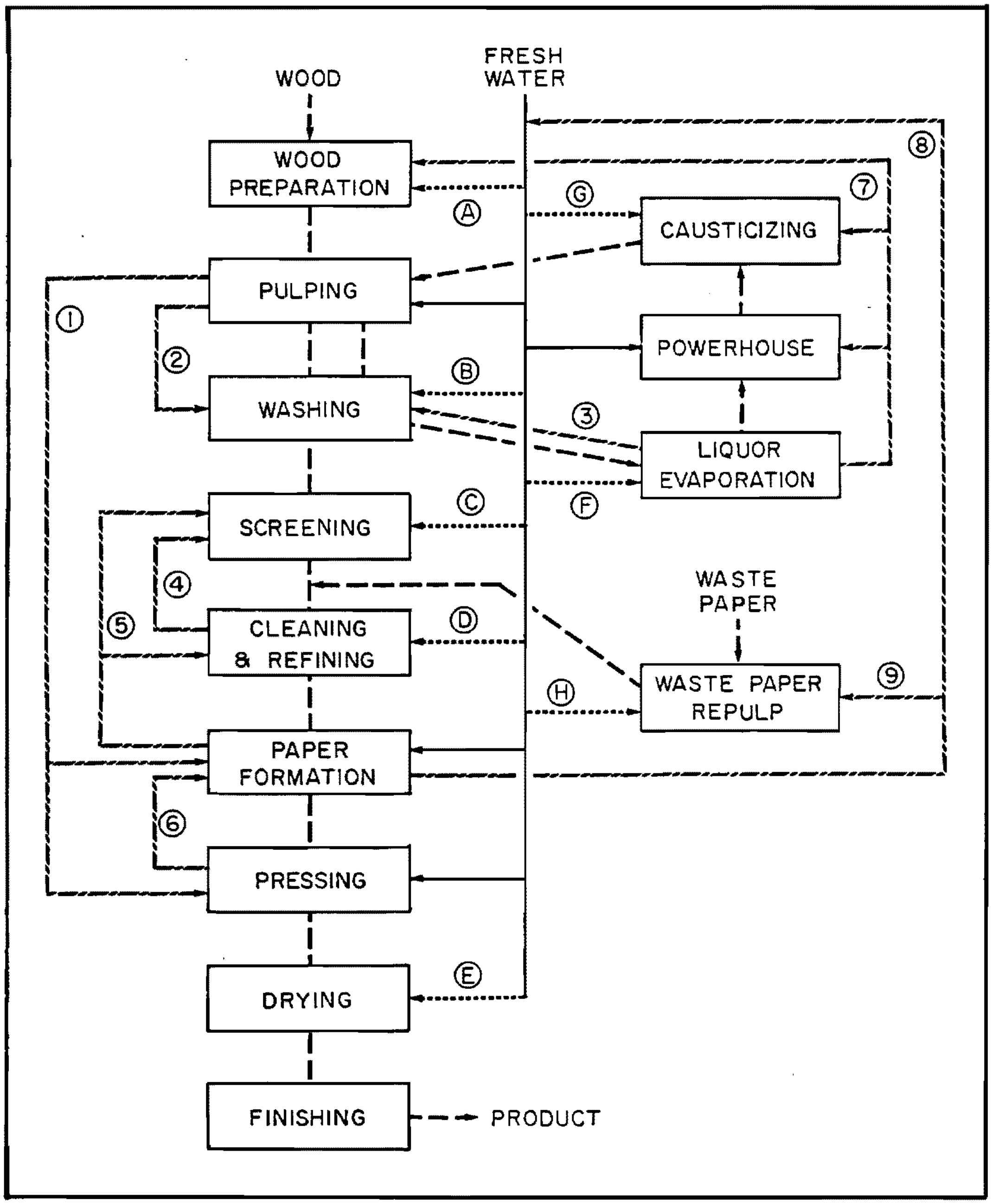


Figure IV-4. TYPICAL UNBLEACHED KRAFT PULPING PROCESS

Table IV-4. UNBLEACHED KRAFT WATER RECYCLING

TYPICAL RECYCLE LOOPS

1- Blow gas condenser cooling water is used for a hot water source for machining showers and dilution (stock heating).

2- Turpentine decanter underflow is used for brownstock washers and knotter showers.

3- Liquor evaporator condensates are utilized for brownstock washing.

4- Cleaner dilution water is utilized in screening.

5- Machine white water is utilized for all dilution/shower water in stock preparation.

6- Press effluents are reused for machine white water make-up.

7- Liquor evaporator condensates are utilized for boiler feed water make-up (clean condensates), causticizing mud washers, lime kiln scrubbers, dreg washing, and wood yard requirements.

8- Almost half of paper machine wastewater can be returned to fresh water clarifiers for process recycle. Doing this requires certain streams, such as those for steam generation cooling purposes, be segregated.

9- Wastewater repulp (3% - 92% solids) can be supplied by paper machine white water.

SUBPROCESSES WITH FRESH WATER USE PRACTICALLY ELIMINATED

A- Wood Preparation: All wood flumes utilize recycle waters. Wet debarking has typically been eliminated. Remaining water requirements are met with process wastewater.

B- Washing: Brown stock washing is typically accomplished entirely with wastewater from the evaporators and turpentine decanter underflow from pulping.

C- Screening: Stock screening is typically relocated immediately upstream of washing. Thus screening dilution comes from weak black liquor. If not, then stock screening retains its place in the process stream (after washing) with high levels of water recycle and water make-up from the decker filtrate. Decker filtrate shower water is principally supplied from evaporator condensates.

D- Cleaning/Refining: Stock preparation waters are met primarily with machine and/or press section white water.

E- Drying: Cooling water for drum bearing lubrication system, air conditioning, etc. is recycled via an evaporative cooler, or cooling water is returned to fresh water reserviors. Repulp of off grade stock may be met with machine white water.

F- Liquor Evaporation: Condenser cooling water is recycled via an evaporative cooler, or cooling water is returned to fresh water reservoirs. Repulp of off grade stock may be met with machine white water.

G- Causticizing: Water requirements for mud washing, dregs filter showers, and lime kiln scrubbers are supplied by other subprocess waste streams. Cooling water is returned to fresh water reservoirs.

H- Fresh water for pulping wastepaper can be supplied by alternate sources like machine white water. If this water is supplied by service water, this stream may be 50% machine white water (clarified) due to recycle loop 9.

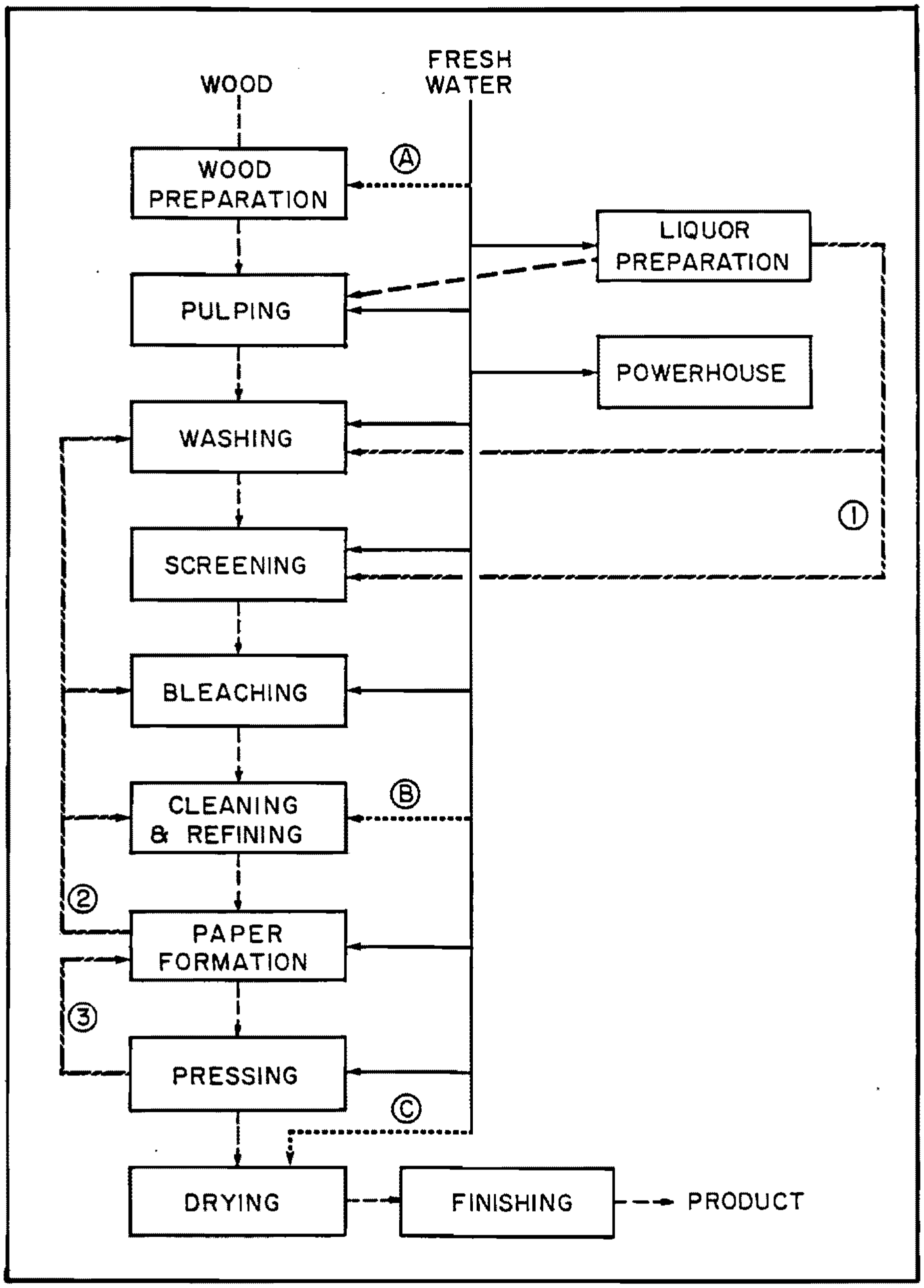


Figure IV-5. TYPICAL CALCIUM BASE SULFITE PULPING PROCESS

Table IV-5. PAPERGRADE SULFITE WATER RECYCLING

TYPICAL RECYCLE LOOPS

1- Wastewater from liquor preparation is available for a variety of purposes, but primarily used for pulp washing and screening.

2- White water overflow is utilized for final bleach stage washing and pulped stock washing. The machine white water also satisfies all dilution and sluicing requirements in stock preparation.

3- Press effluents are reused for machine white water make-up. Mills that have problems with paper quality due to felt hair contamination often recycle press effluents for stock dilution in the cleaners.

SUBPROCESSES WITH FRESH WATER USE PRACTICALLY ELIMINATED

A thru C- Typical with all types of paper/pulp mills elimination of fresh water use in various subprocesses is accomplished by converting to dry wood yard processing and substituting adequate waste water streams for fresh water in wet processes. Cooling water is converted from once through systems to recycle via air-to-water coolers or injecting into process water systems.

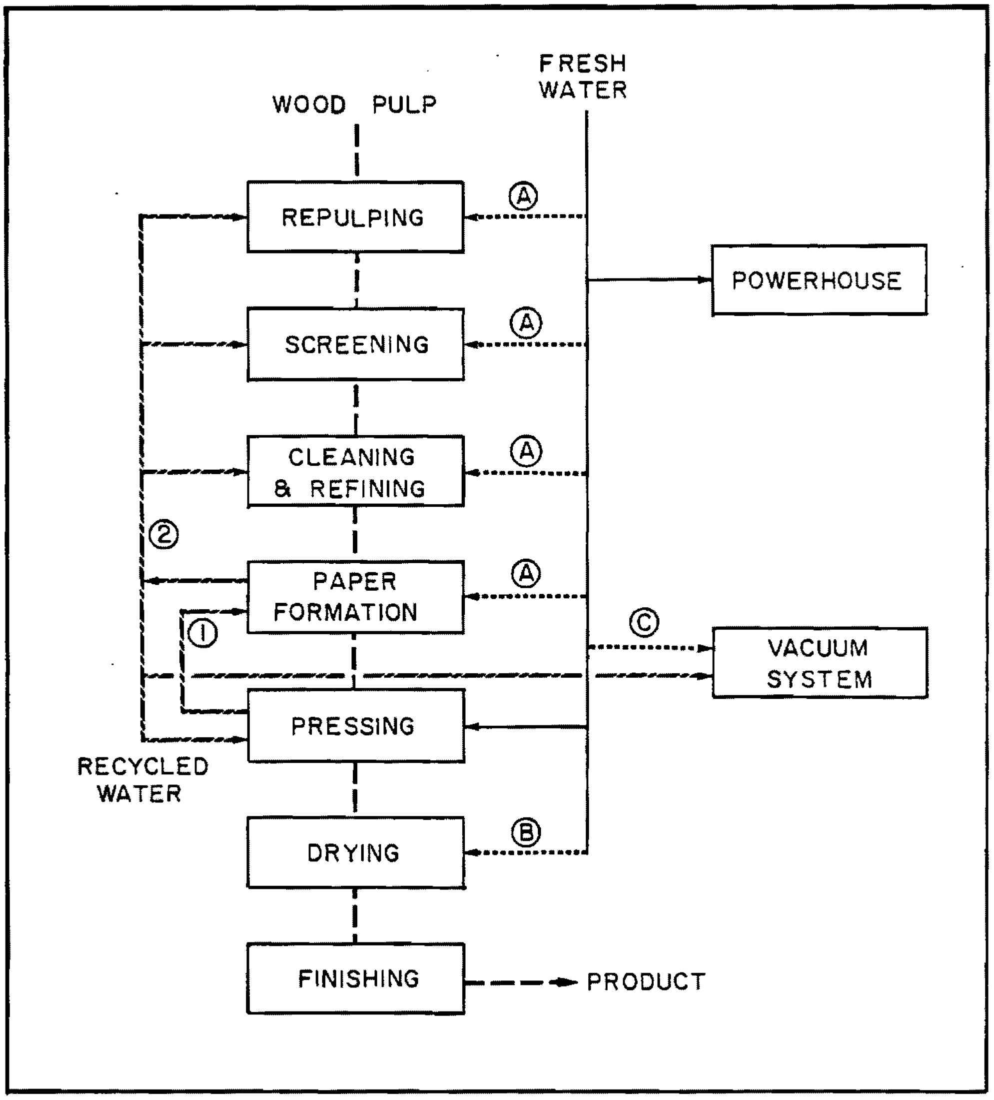


Figure IV-6. TYPICAL NONINTEGRATED FINE PAPER PROCESS

Table IV-6. NONINTEGRATED FINE PAPER WATER RECYCLING

TYPICAL RECYCLE LOOPS

1- Press effluents are utilized for machine white water make-up.

2- Paper machine white water is utilized for all dilution/shower water in repulping, screening, cleaning, and low pressure felt showers.

SUBPROCESSES WITH FRESH WATER USE PRACTICALLY ELIMINATED

A- Repulping and stock preparation waters are met primarily with machine and/or press section white water.

B- Cooling water for drum bearing lubrication system, air conditioning, etc. is recycled via an evaporative cooler, or the cooling water is returned to fresh water reservoirs. Repulping of off grade paper stock may be met with machine white water.

C- Vacuum system fresh water requirements may be greatly reduced by the utilization of machine white water or heavy recycle via an evaporative cooler.

all but one mill visited, these conservation and reuse/recycle measures were seen.

Digesting and brown stock washing systems (see Figure IV-2) are the most prominent in utilizing large quantities of wastewater in process streams. Of the mills visited, 14 used evaporator clean condensates for the last stage of brown stock washing. Several mills also utilized a variety of wastewater streams such as bleach effluents, accumulator dirty hot water, or evaporator dirty condensates.

Those mills employing a decker after the washing and screening processes generally used freshwater for at least part of their water requirements in the shower and repulper dilution operations. The balance of the water was recycled from a variety of sources including evaporator clean condensates, pulp/paper machine white water, and bleach plant chlorination effluents. Mills that were more technically sophisticated in water reuse/recycle technology operated brown stock washing and screening entirely on recycled waters. Those mills that extensively utilize wastewaters in this area not only have below average freshwater consumption but also they enjoy improvements in reduced scaling or pitch buildup (and, when applicable, lower chlorination costs in bleaching).

Recycle/reuse applications in the bleaching area shows the greatest variation in sophistication of all mill processes (see Figure IV-7). In the mills visited it was common to see extensive amounts of freshwater used in bleaching for a variety of reasons. However, constraints on use of washwaters are not as stringent as commonly expressed by some mill personnel because certain mills were found to reuse/recycle water extensively. Countercurrent or jump stage washing (see Figure IV-8) practices are well known in the industry today and yet many mills are only now beginning to employ these techniques because of the expense of upgrading materials to combat corrosion.[7] Two mills visited were found to utilize paper/pulp machine white waters coupled with forms of countercurrent or jump stage bleaching processes. These mills also utilized chlorination effluents for unbleached stock dilution and generally employed lower quality water for washing and decker showers. One mill indicated that the prime motivation for this practice was chemical/thermal energy savings, which is supported in the literature.[8]

Most pulp/paper machine areas operate quite similarly in that large quantities of freshwater are utilized for showers and vacuum pump sealing (see Figure IV-9). Many of the mills visited employed some white water showers while some had abandoned the practice due to additional maintenance costs required to maintain such systems. One unbleached Kraft mill visited, was operating one machine on 50% recycled white water and a second on 100% of the first machine's white water. Because the mills effluent treatment costs were partially based on discharged volume, this was a major motivating factor driving it to achieve the lowest freshwater consumption of its production class. Mill spokespersons indicated machine close-up also yielded substantial energy savings.

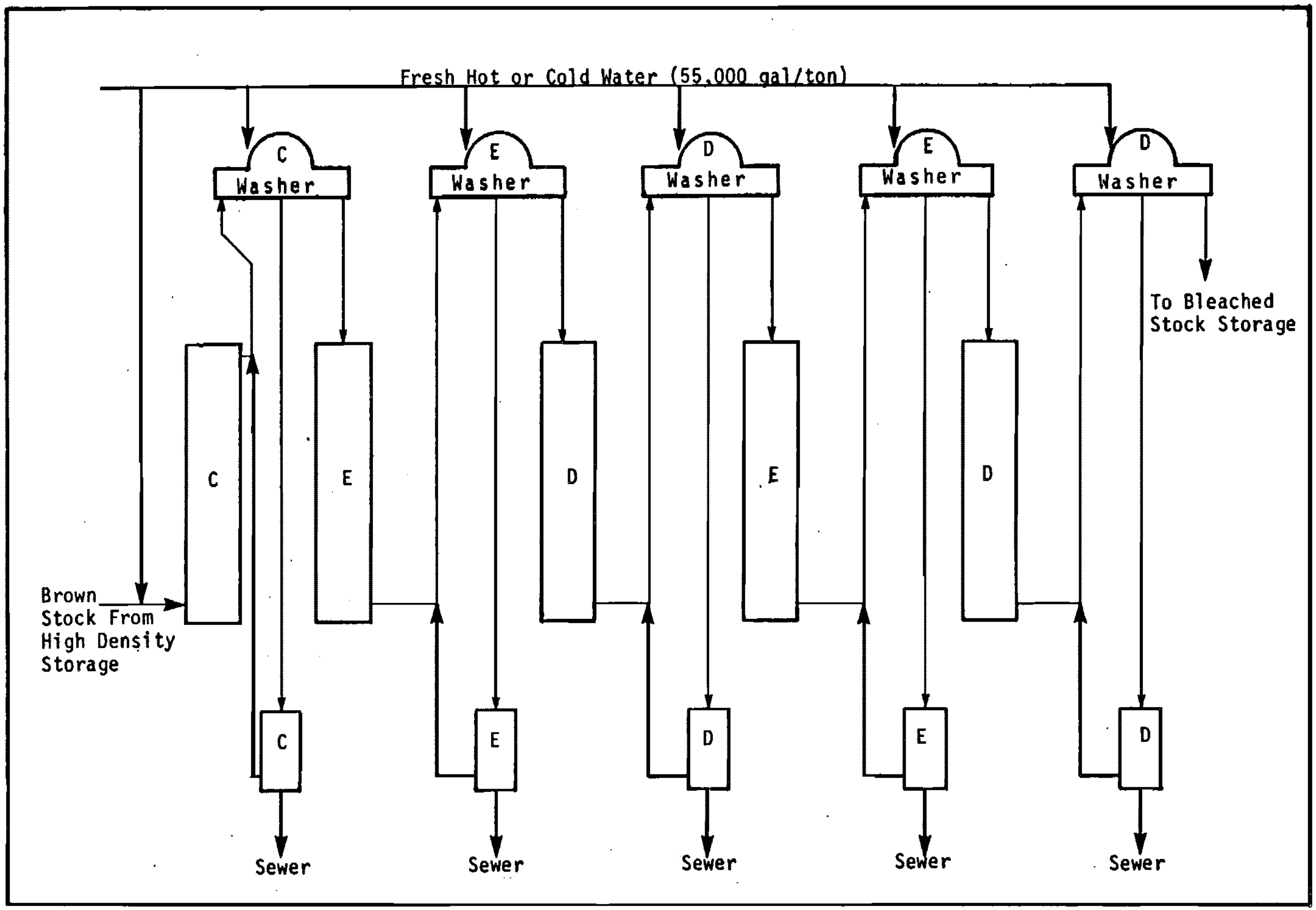


Figure IV-7. TYPICAL BLEACHING PROCESS WITH CONVENTIONAL RECYCLE FLOWS HIGHLIGHTED

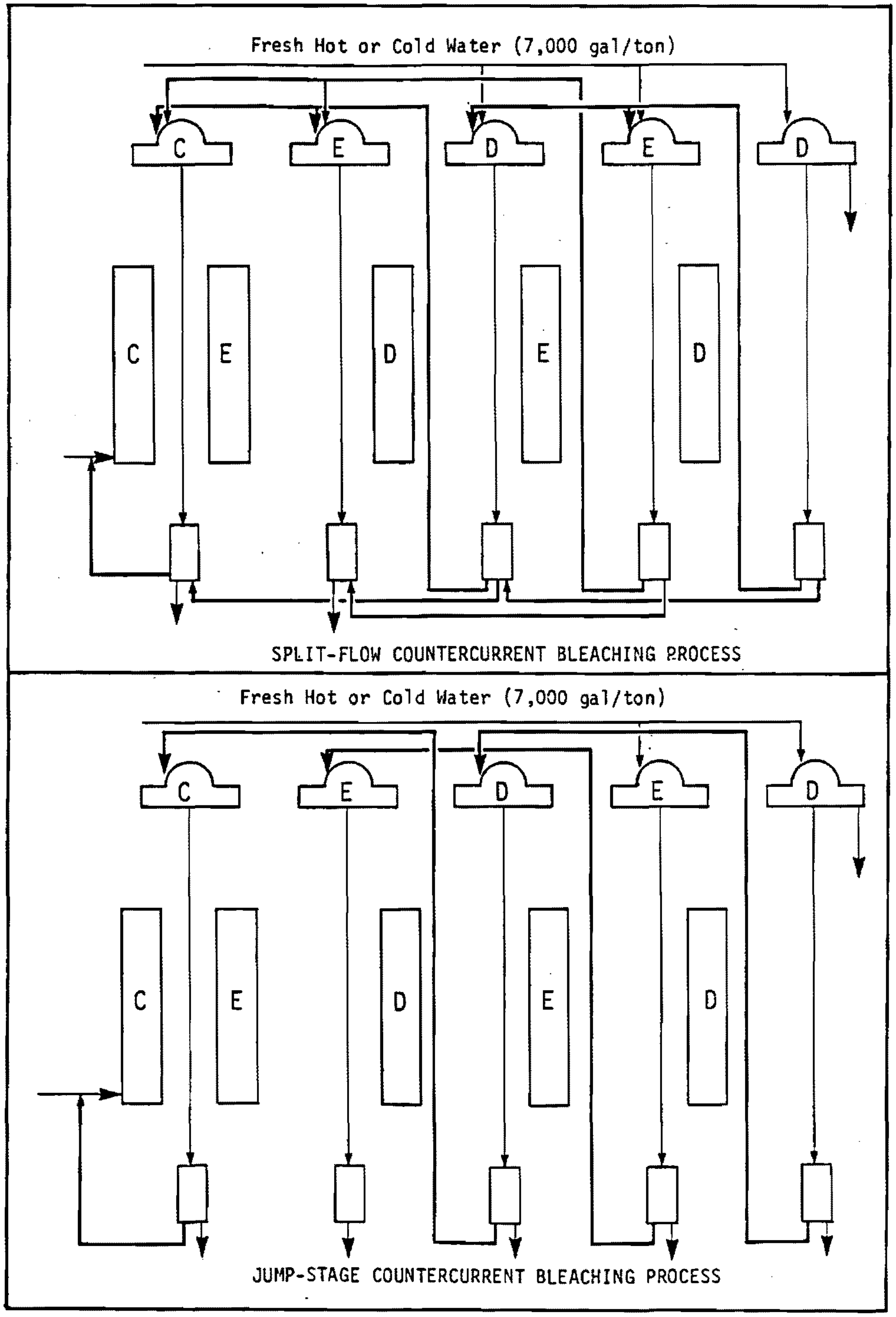


Figure IV-8. HIGH LEVEL WATER RECYCLE SCHEMES FOR BLEACHING

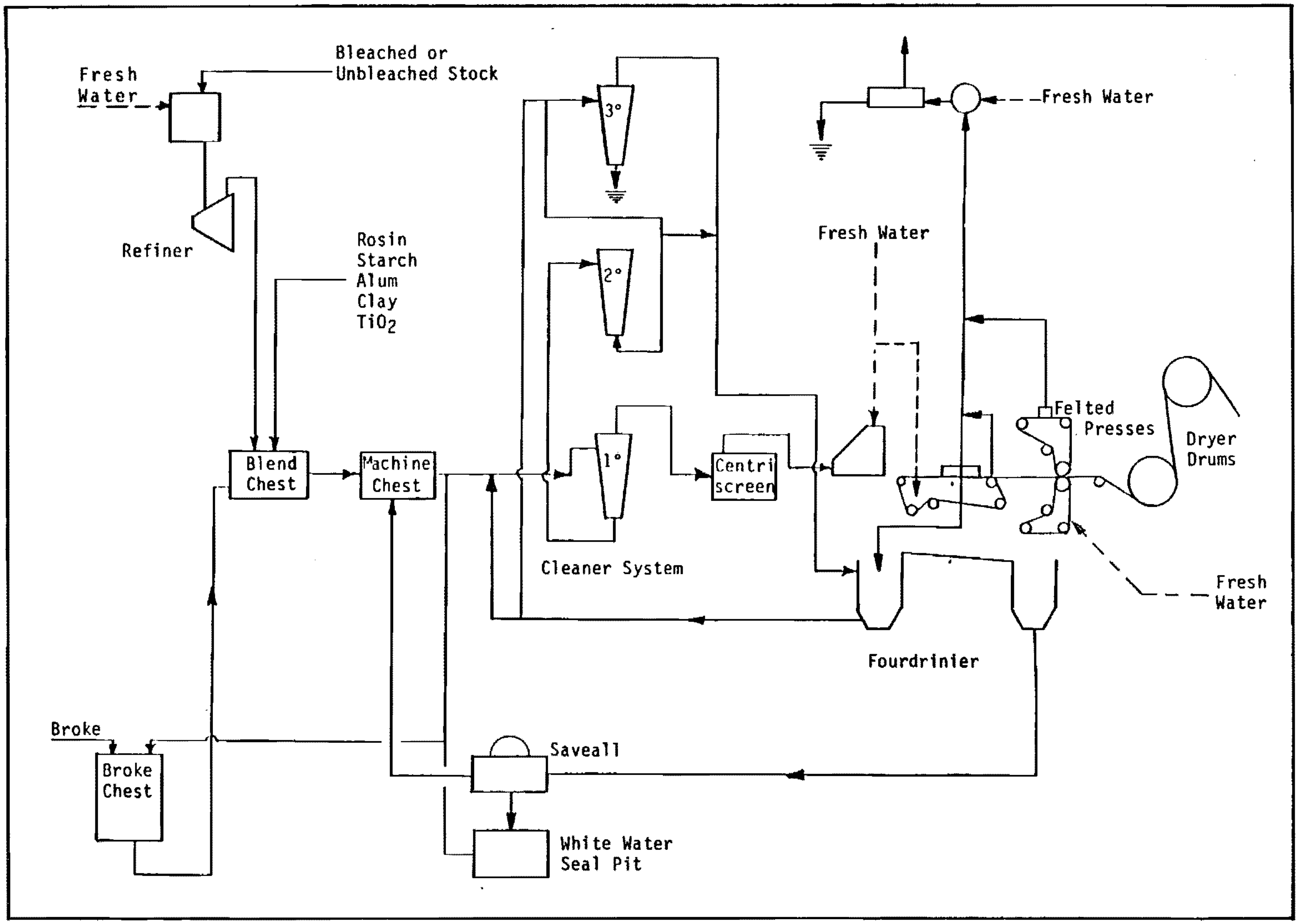


Figure IV-9. TYPICAL FOURDRINIER-TYPE PAPER/PULP MACHINE

WATER RECYCLE/REUSE CONSTRAINTS

Several publications quantified specific mill constraints with regard to water reuse/recycle.[5,9,10,15,16,19,21,27] These works provided a rich resource of data on specific operational criteria which various mills require for satisfactory operation. For example, information on the limits of pulp fines, calcium carbonate, and corrosives in machine white water systems identified quality requirements for specific mills (and specific pulp/paper types). The survey conducted during this study allowed an evaluation of the qualitative constraints limiting additional reuse/recycle. This information coupled with published works provided insight into specific problems facing mills in the United States and helped in the evaluation of such problems. The limitations for water reuse in the various production categories showed many common traits. Paper machines, for example, were found to be quite similar among mills from a process point of view. Consequently they were found to share common problems associated with water reuse/recycle.

Regional Constraints

As reported in the Nation's Water Resources",[43] a comparison of water supply and water use data shows that the overall water supplies of the nation are generally sufficient to meet projected water needs for all beneficial purposes. However, there are water problems in most of the 21 water resources regions, and more particularly there are local problems of varying intensity in nearly all of the 106 subregions. Functional problem areas most commonly encountered by the pulp and paper industry include:

- Inadequate surface water supply
- Overdraft of groundwater
- Thermal pollution of surface water and groundwater

In certain regions the total streamflow is very large when compared to withdrawals. Yet problems still occur because of variations in both area water distribution and the timing of runoff. This is the case in some areas of the Pacific Northwest. Even though this area receives some of the highest annual precipitation for the country, most of it falls in the winter months. During the dry summer months, when stream flow is reduced, water withdrawals from storage reservoirs is often necessary. These mills have active conservation programs to enable the reservoir to last through these periods.

Problems can also occur with groundwater supplies, even in areas with large supplies. The southeast Georgia/northeast Florida area is located on some of the country's most abundant and productive aquifers. Several large pulp and paper mills, local municipalities, and other large volumes water-using industries located in the area are pumping large quantities of groundwater. These heavy withdrawals have lowered groundwater levels resulting in increased pumping costs. Also, where pumping rates have approached recharge capacities, salt-water intrusion is becoming a major problem. Deteriorating groundwater quality due to the increase in chloride concentration could prohibit its use as a domestic and industrial supply. Concern over the groundwater supply has motivated a joint effort between the communities and the industries to reduce water withdrawals.

One further regional constraint associated with the pulp and paper industry is the temperature of surface and groundwaters. Mills located in the south and west showed a seasonal variation in water reuse/ recycle simply because of high water temperatures for the warmer months. High humidity ratios during the summer season in southern mills caused many to rely on freshwater for practically all of their liquor evaporator cooling requirements. Since most mills subsequently used the cooling water in mill processes, they typically utilized higher volumes of freshwater for processing. This problem intensifies with elevated temperatures in paper/pulp machine white water systems. Most mills limit white water temperatures to around 135-150°F. Additional freshwater (instead of recycled white water) is therefore required for cooling during the summer months to maintain white water temperatures. Personnel in an average size mill have indicated that the net increase in freshwater usage for summer cooling accounts for an additional 2 MGD or about 1600 gal/ton.[1]

The additional freshwater requirements for summer operation correlate well with those mills utilizing surface water as their primary source. During summer periods, this source of water sometimes exceeds 85°F in the south while in the northern regions such temperatures generally remain below 65°F. Only two mills visited that withdrew water from deep wells required additional cooling water during the summer months. Both of these plants, however, experienced substantial groundwater temperature increases during the summer.

Environmental Constraints

Until recently, federal activity in implementing environmental legislation was a motivating force in encouraging the reuse and recycling of water. Many mills seized the opportunity, created by requirements to comply with strict effluent discharge standards, to implement recycle/reuse measures which avoided more costly investments in waste treatment facilities. Some mills were forced to make heavy investments in treatment facilities thereby reducing the capital available for recycle/reuse programs, but by and large, recycle/reuse was almost always carefully studied as an alternative to such investments.

Recently, however, a series of events has created an air of uncertainty regarding future environmental legislation. Standards originally proposed for implementation in 1984 have come under criticism by a number of industries, including the pulp and paper industry.[44] Due to legal constraints, the proposed standards have been indefinitely delayed. The impact of delays is the delay of industry expenditures that are justified primarily for their ability to meet the proposed legislative standards, included in which are undoubtedly some reuse/recycle programs. Until a final resolution is reached on this matter it is unclear exactly how environmental constraints will affect recycle/reuse efforts.

No mills visited operated under regulatory codes restricting effluent volume. However, almost all mills recognized the additional treatment costs associated with excessive effluent volume, including mills that utilized municipal waste treatment systems. One mill used the cost of treatment to justify extensive modifications to processes for minimum effluent volume. It has subsequently found that significant energy savings were achieved as an indirect result of the project.

Technical Constraints

To clarify the basic technical issues that affect the capability of mills to recycle water, the following section addresses those problems cited in the literature and mill visits that are of paramount importance. These constraints are divided among the major plant processes of interest.

Paper/Pulp Machine

The paper/pulp machine is one of the largest freshwater consumers in the industry and is second to no other process in terms of its potential for conservation.[6] Practical experience with reductions to freshwater consumption levels below 5000 gal/ton, however, have proven troublesome due to increased dirt, scale problems, and corrosion.[5,10,21] These problems and many others must be addressed for widespread practice of high levels of water reuse/recycle. Figure IV-10 shows a concept for a low freshwater consumption paper machine.

Conversations with industry representatives has yielded a significant amount of insight into the types of problems involved in reusing/ recycling water on the paper/pulp machine. Below are listed the problems that were mentioned with supplemental information included:

- Shower Plugging - The most common problem cited with machine water recycle is the expense and attention required to maintain white water showers. Shower plugging, as a result of upsets in white water filtration equipment and dissolved solids buildup, is the primary cause of this problem. Several mills, after initiating recycle schemes, have actually reversed this activity to eliminate the cleaning requirements and maintenance costs of white water filtration equipment. However, mills that presently have a strong motivation for recycling are finding ways to utilize white water extensively on the paper machine. Here, showers with larger orifice sizes (0.05" - 0.06") incorporated with 60 mesh strainers have provided satisfactory operation. Studies on shower plugging have indicated that the problem is primarily a result of white water particles longer than 0.001". In the absence of these long

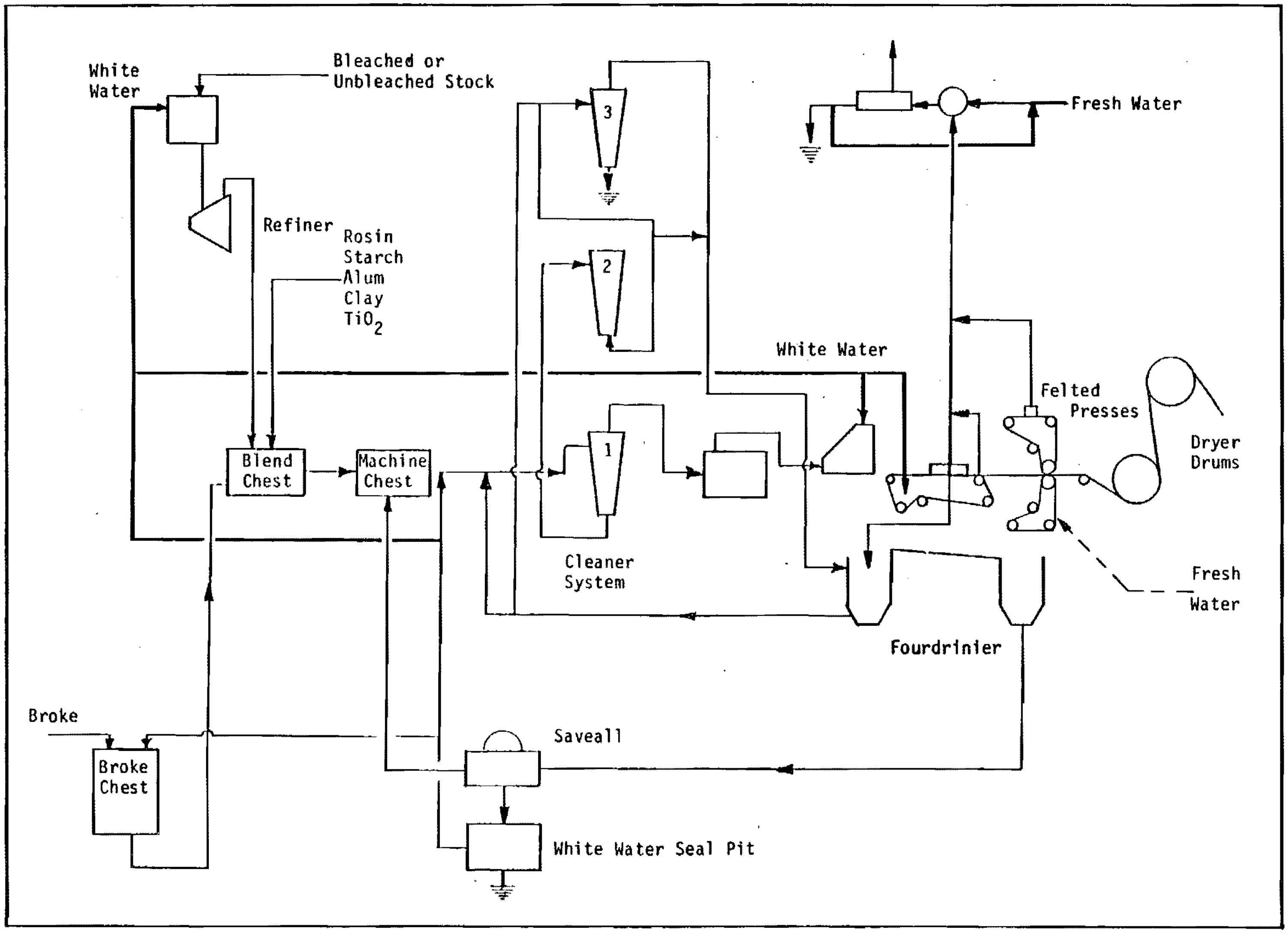


Figure IV-10. TYPICAL FOURDRINIER-TYPE PAPER MACHINE SHOWING A HIGH LEVEL OF RECYCLE fibers, levels above 3000 mg/l of contamination have worked satisfactorily in conjunction with conventional self-purging nozzles.[11]

White water applications in showers for felt conditioning have been far more limited. Only one mill is known to use white water successfully here. This mill recirculates white water to the freshwater clarifiers for fiber flocculation. This system has resulted in a 50/50 mixture of white water/freshwater and yielded a low solids content which has eliminated inadequately cleaned felts that are associated with high levels of recycle. Casey[6] cites the use of high pressure (ultra high pressure in comparison to what is commonly found in the industry), intermittent showers as a more viable approach for felt conditioning. Freshwater usage with this system is typically less than the common freshwater requirements for all felt conditioning. As documented by Appleton Felts, these low volume showers can utilize pressures in the neighborhood of 500 psi without a decrease in felt life.

- Corrosion - Mill spokespersons who participated in this study indicated that excessive corrosion from increased machine white water recycling did not pose a significant problem in their mills. Their comments were in disagreement with many previous studies[12] which may be an indication that problems associated with corrosion are underestimated. This is particulary true on those components that are predominantly composed of carbon steel such as vacuum systems.[13] Documented evidence exists on excessive corrosion problems[14] during machine acceptance testing while using certain recycling schemes.

  Mill visits did indicate that numerous measures designed to combat corrosion have been implemented. These measures include extensive use of fiber reinforced plastics and of stainless steels for many of the machine and white water system components.

  With the extensive amount of work that was observed in this area, it is expected that corrosion problems associated with water recycle will be less of a limitation than was determined only a few years ago.

- Deposits - The accumulation of scale or pitch appears to be excessive only in certain mills. Those which utilize substantial quantities of size are more notably affected by these problems as they increase their recycling of white water.[15] This is a consequence of reduced sizing efficiency which creates a need for high alum concentrations in the white water system. The net result of this condition is the formation of chemical slime (from the precipitation of aluminum hydroxide) which leads to wire and felt clogging.[18]

Scale problems associated with the precipitation of magnesium and calcium carbonates are usually caused by high hardness water supplies. Those mills affected by this condition usually control this problem by utilizing white water additives (dispersants) or by softening the machine freshwater supply. Several mills have addressed the problem by obtaining water from an alternate supply. Thus, high hardness surface water is utilized for some mill functions while higher quality water from lakes and wells are kept segregated and utilized for machine applications. However, some mills were found utilizing freshwater on machines with hardness values in excess of 400 ppm without any problems of scale buildup.[17]

Rosinous pitch buildup is usually associated with liquor carryover from digesting and the improper use of sizing. These two problems are typically not identified[5] as major concerns since they can usually be limited through better operations control and proper sizing application.[18] Sizing usage has been studied for a number of years; thus, a wealth of information concerning application techniques and control exists.

Problems associated with deposits are very site specific in that freshwater quality and the nature of the mill operation may or may not lead to complications.[5] No correlation was found between freshwater quality and deposition problems among mills visited within a given geographical region.

o <u>Biological Growth</u> - Present practices of white water recycling have given most pulp/paper producers considerable experience in dealing with the problem of biological growth.[6] This problem is usually associated with odor in the final product and is often prevented by adding chlorine or other biocides to the wire pit. With additional efforts to close up the paper machine, however, there are additional complications associated with an increase in machine operating temperature. Mills operating their machines at ambient conditions (80-100°F) will likely experience a shift in bacteria population from the mesophyllic to thermophyllic.[21] Thermophyllic bacteria usually produce spores and are more difficult to control.[19] Stagnant white water in stock preparation areas aggravates the biological growth problem. Therefore, process changes may be required (along with a good biocide program) to control biological population growth.[20]

  Some mills surveyed indicated that higher temperatures actually made biological growth easier to control thus indicating that the problem is again site specific. Most mills agree that bacterial counts of 1×10^6 bact/ml is the upper limit before problems develop.[6]

o <u>Paper Color</u> - Several mills with multiple paper/pulp machine have interconnected white water systems to better manage overflows associated with shutdowns. Others operated multiple machines totally independent of each other to reduce the complexity of the operation and to better control paper color. Whichever approach is employed, the capability to recycle white waters is equally strong since interconnected machines only provide better overflow protection in return for greater operational complexity.

Recycle of colored white water is not viewed as introducing any new problems that are unique to colored paper production. Some mill spokesmen indicated they would consider increased water recycle as a benefit towards paper color control, but they admit that correction of off-quality paper would take longer. Martin-Lof[22] has indicated that increased recycle actually improves the optical and mechanical properties of the sheet.

o <u>Machine Clothing</u> - White water reuse on wire showers is commonly practiced in many mills today. Because these showers are generally low pressure with large orifices, satisfactory operation without highly complex white water cleaning systems is possible. Mill personnel have indicated that this measure is cost effective for energy conservation (on heated machines) and as well as for chemical conservation. They also have indicated that scale buildup due to minerals in freshwater is eliminated since the shower water pH matches the wire pH. Hot machines also experience extended wire life due to less thermal shock on the wire.

These same benefits would probably apply to felt conditioning if the problem of shower plugging in the smaller sized orifices could be overcome. As mentioned previously, only one mill was found to satisfactorily utilize such white water for felt conditioning. This was accomplished by recycling machine white water to the freshwater clarifiers thus yielding mill service water which contained only 50% machine white water.[9] Casey[6] indicates that using low volume, high pressure (500 psig), intermittent showers is technically a more sound approach.

Felt hairs entrained in press effluents pose a notable problem for recycle.[23] Several approaches can alleviate this problem. Some mills have found the utilization of high synthetic content felts to be effective in reducing hair loss.[6] Use of these felts in conjunction with rotary cylinder screens of 140-120 mesh[24, 25] has proven effective in removing this contaminant. Other mills segregate press effluents and utilize it for dilution prior to refining.[14] This enables the refiners to reduce the felt hairs to a harmless length, thus enabling them to exit the system in the final product.

In conclusion, it is expected that the use of white water for felt conditioning will be extremely limited unless more satisfactory methods for fines removal or for improving showers tolerance of fines is developed. However, the incentive for this development work exists since the utilization of low pressure (200 psig), high volume white water showers offers significant benefits in terms of felt life and reduced accumulation of minerals and slime.

A more immediate solution being proposed to mills[6] employs very high pressure (500 psig) intermittent freshwater showers. Development in the field of sonic air/stream nozzles for felt conditioning offers an alternative to freshwater use. Preliminary studies indicate this technique to be effective in providing adequate felt cleaning.[26]

- Salts and Chemical Treatments - Since many salts and chemical treatments require high quantities of fluid flow, with little retention of the fluid on the sheet, much of the solution ends up the white water recycle loop. Concentrations of salts in the range of 4000 mg/l[6] have not adversely impacted pulp/paper physical or optical quality. These high concentrations should reduce biological growth thereby reducing biocide costs.[21] Corrosion is expected to cause the greatest impact, but with the improved material grades witnessed at many mills, theproblem should be minimal.

- Seal Water - Most mill spokespersons agree that the recirculation of white water for sealing in vacuum pumps is a good recycle approach as long as sufficient cooling is performed to maintain vacuum pump efficiency. Of the mills visited, many either employed this technique or were in the process of incorporating it. Because most plants utilize carbon steel vacuum pumps and associated piping, it is expected that corrosion inhibitors will be necessary to assure adequate pump life. One mill[27] incorporated a cooling tower water recycle loop, with freshwater make-up, as a means of satisfactorily reducing freshwater consumption and corrosion.

Bleach Plant

Bleaching technology has become the focal point of research in recent years. Motivations include chemical and energy cost reduction, effluent reduction, and lower freshwater demand. Environmentally, bleaching processes account for the largest single source of organic wastes posing problems in its potential toxicity to wildlife. These problems are caused by the chlorinated aromatic compounds emitted from the first extraction stage and the chlorination stage.[6, 28] Freshwater consumption in bleach plants as high as 60,000 gal/ton has been reported and pulp losses can be as high as 10%.

Schemes such as recycling effluents from the bleaching stage back to the black liquor evaporators[29] have not been economically attractive because the organic concentration is only about 0.25 lb/ft^3,[6]. Therefore, more heat for evaporation is required than is yielded during combustion in the recovery furnace. Notable levels of recycle in bleaching processes are also limited due to the additional chemical costs and corrosion.

A conventional chlorination stage requires almost 5600 gal/ton of freshwater, which frequently equals the total requirements for the subsequent stages combined.[6] This represents a substantial thermal energy demand because the stock is received hot from washing and screening, is subsequently cooled to near ambient for chlorination, and then heated back up to about 165°F for the following caustic extraction stage.[30] Substantial amounts of freshwater are required not only for cooling but also for dilution, since stock supplied to the bleach plant can have a consistency as high as 14% with chlorination typically requiring a 3% consistency.

Much research has been performed in the area of improving the energy efficiency of this stage and in reducing freshwater requirements. The more notable efforts include:

- o Recycling chlorination effluent
- o Utilizing high consistency gas phase chlorination
- o Utilizing recycle waters from counter current washing
- o Using an oxygen-ozone stage instead of chlorination

Each of these technologies offer specific advantages but are highly site specific when determining cost effectiveness.

The recycle of chlorination effluent for dilution of incoming stock, as shown in Figure IV-8 , is finding greater acceptance in the industry today. It offers a low capital means of reducing chlorine costs and eliminating pitch buildup in unbleached stock lines.[31] This step alone can reduce freshwater consumption by as much as 1100 gal/ton. This approach generally causes an increase in chlorination temperature thus requiring the input of small amounts of chlorine dioxide to protect against fiber degradation.[32] The primary limitation to widespread application is the increase in material grade of unbleached stock piping to protect against excessive corrosion.[33]

Along with recycled chlorination effluent, some form of bleach plant countercurrent washing was found in many of the bleached Kraft mills visited. Countercurrent washing in general is justified chiefly by steam and possibly chemical savings. It also results in a net reduction of freshwater consumption and effluent volume. The ultimate in direct countercurrent bleaching as discussed by Rapson (see Figure IV-11) in 1967, utilizes a large fraction of chlorine dioxide in the chlorination stage (more accurately labelled a chlorine dioxide with a chlorine stage).[34] The D_CEDED configuration is able to operate with 8000 gal/ton of freshwater or about one-third the normal water requirements.[35] This system will soon be fully developed at the Great Lakes Paper Co., Thunder Bay, Canada. Even though countercurrent requires

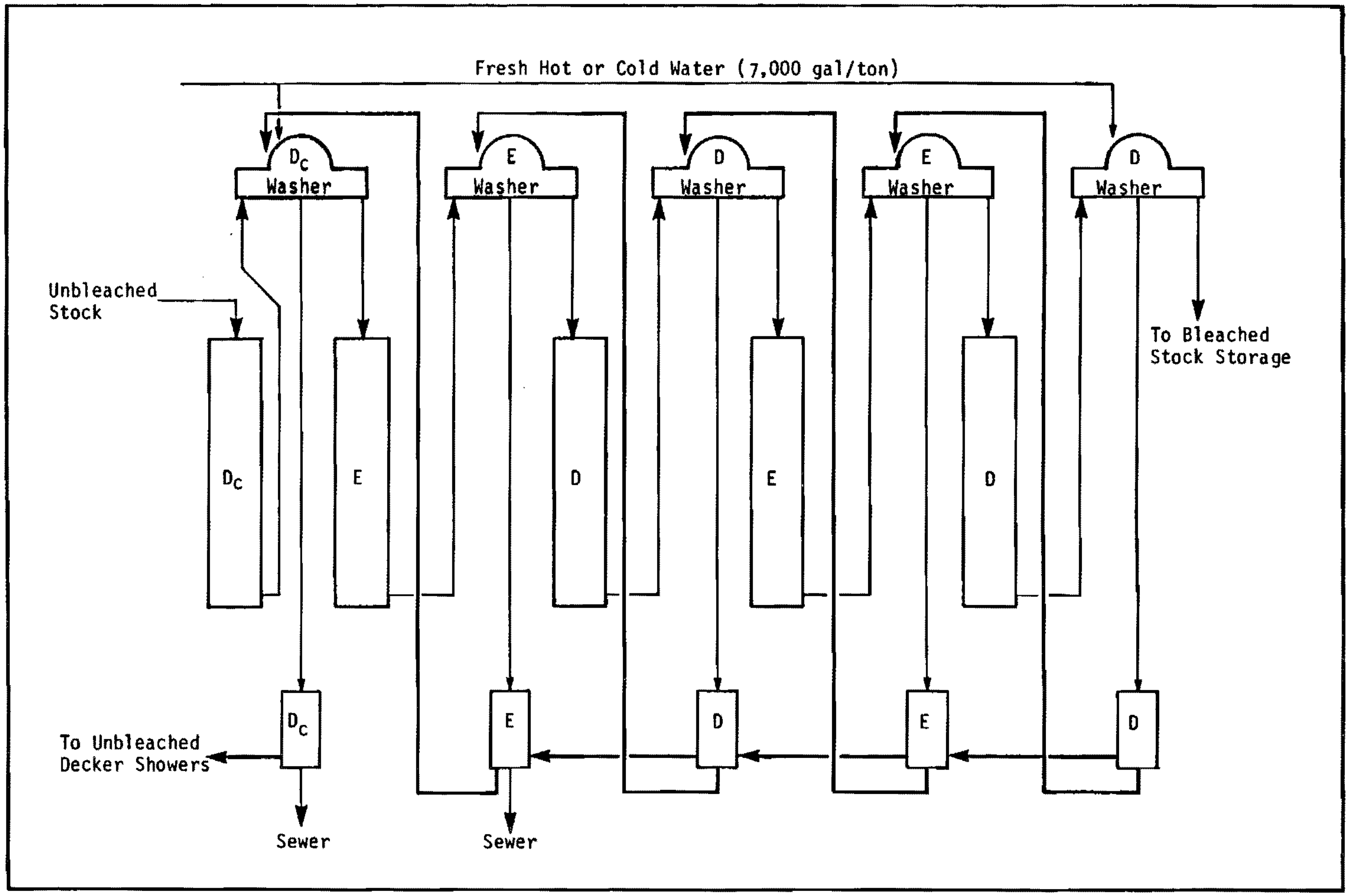


Figure IV-11. DIRECT COUNTERCURRENT BLEACHING PROCESS WITH HIGH DENSITY FIRST STAGE FOR MINIMUM FRESH WATER REQUIREMENTS very high grade stainless steels like 317ELC[6] for corrosion protection from the presence of chlorine dioxide in the wash waters, an economic justification is expected on energy savings alone.

Few mills visited used any form of countercurrent washing. Upgrading bleach plant materials to meet anticorrosion requirements is costly, and low water volume washing requires increased chemicals. However, with lower chemical and energy costs, many plants are studying less capital intensive, high payback methods of water recycle. Jump stage or split flow systems as shown in Figure IV-8 offer promise in reducing freshwater consumption.

Eight mills interviewed already utilize machine white water for various bleach shower applications. This is fast becoming the industry standard, especially on the last chlorine dioxide washer and can account for a reduction in freshwater usage of almost 2000 gal/ton. A major barrier to greater recycling is insufficient knowledge of the effects of chemical additives in machine white water on the various bleaching stages. In modifying existing bleaching systems, the more economical approach is the maximum utilization of machine white waters.

Studies have been conducted on the use of bleaching effluents in lieu of freshwater at other parts of the mill. These include the system as proposed by Rapson. It uses two-thirds of the effluent in brown stock washing and the balance for various purposes in the causticizing area, such as lime kiln venturi scrubber water, lime slaking, green liquor preparation, and white liquor dilution. Applying this technology would be prohibitively costly due to the extensive modifications required for existing mills. However, many components of this approach appear to be economically attractive in that equipment modifications are minimal.

Bleach plant effluent recycling for brown stock washing imposes a buildup of chlorides in the liquor system which can cause accelerated corrosion on recovery furnaces. Yet, mills reporting white liquor salt concentrations of 70 gm/l or higher have operated satisfactorily for years.[35] Poor pH control in the weak black liquor system will result in the precipitation of any calcium in the effluents. Extensive reuse for brown stock dilution will likely yield an increase in bleach plant chemical usage due to the presence of higher concentrations of dissolved organics.[6] With over 25 lb BOD/ton of possible effluent utilized, a substantial reduction of BOD_5 emissions for the bleach plant is possible,[6] thus yielding a savings in waste treatment costs.

A more applicable scheme for reducing the volume of bleach plant effluents from existing mills is through more extensive recycle for washing. Coupled with the partial utilization of bleaching effluents (less than one-third of the volumetric flow) for operation in the causticizing area, this system should be more promising in terms of economic incentives. Mill visitations found little or no reuse of bleaching effluents. Only a small amount of usage for woodyard flume make-up and assorted showers was found.

Sodium or ammonia base sulfite pulping is a better adapted process for bleaching effluent recycle for brown stock washing.[36] Because the first bleaching stage for this process can be a hot caustic extraction, brown stock washing with this effluent is readily adaptable with the effluent being concentrated and burned with the cooking liquors. This process is readily adaptable to dissolving pulp grades which are cooked to a lower k number. Unfortunately, this recycle scheme is not feasible for calcium or magnesium base liquors.

Pulping, Washing, and Screening

With the exception of sodium or ammonia based sulfite processes, recycle of bleach plant effluents for more than unbleached stock dilution is extremely limited. The primary costs of this approach to water reuse include chemical costs to maintain wash water pH above 11 (to minimize scaling and corrosion) and to prevent concentration buildup of salts. Both Kraft bleached and unbleached mills need very little freshwater in pulping, washing, and screening, however. The primary source of brown stock washwater and stock dilution water for existing mills appears to be from dirty condensates obtained from the liquor evaporators and the digesters. Although our survey showed no mills practicing this in its entirety, the technical limitations were found to be few and the benefits of chemical savings, energy savings, and a reduction in BOD_5 loading on the sewer were significant. Almost all the mills visited utilized some form of condensate recycle in the pulp washing and screening operation. Problems associated with foaming and poor washing often limit condensate recycle. Four mills visited actually utilized their clean condensates for washing and/or liquor preparation.

Dirty condensates, which are composed of the digester blow steam, liquor evaporator-condenser effluent, and turpentine decanter underflow, account for approximately one-third of a Kraft mill's BOD_5 effluent.[37] These effluents contain low molecular weight organics (of which 80% is methanol), other alcohols, ketones, phenolic substances, sulfur compounds, and turpentines.[38] The volume of this flow is adequate and suitable not only for brown stock washing, but also for causticizing needs such as lime mud washing, green liquor preparation, lime slaking, and kiln venturi scrubber make-up.[39]

Successful recycling of process dirty condensates for high quality washer dilution usually requires steam or air stripping to eliminate washing problems and odor problems from tank vents and vacuum pumps.[40] Usually the low molecular weight organics stripped from the condensates are subsequently burned in the lime kilns or recovery furnace.[41] Stripping also reduces wet strength resin requirements for the paper sheet.

Full condensate recycling technology is not present in the industry today primarily due to poor economic incentives. Energy savings, especially when condensate stripping is employed, are limited and therefore justification is very weak. Reuse of condensates is primarily employed as a means of meeting current effluent permits for those mills that are limited or nearly limited on waste treatment capability. As mentioned earlier, many mills utilize clean evaporator condensates for brown stock washing instead of returning them to the boiler feedwater system. This is a very poor water reuse scheme since a very high quality water supply is being utilized where dirty condensates are equally suited. But, because of the fear of contaminating boiler feedwater, most mills elect to use these condensates for brown stock washing. Only one mill visited utilized clean evaporator condensates for boiler feedwater make-up. The mill spokesman contended that proper instrumentation and good maintenance make clean evaporator condensate reuse in the boilers cost effective, based solely on energy savings.

Several mills expressed a concern evolving around poor washing and excessive fouling of evaporators resulting from using dirty condensate. However, Casey[6] has indicated that the major problem associated with evaporator scaling is the result of an insufficient supply of active alkali in the black liquor to maintain the pH above 12. If this problem occurs, it results in lignin precipitation in the evaporators. Lignin depositing also occurs when evaporators are operated at temperatures exceeding 250°F.[42] This problem is common since higher evaporator tempera tures are used in exchange for high capital costs of larger evaporators required for a given production rate. Other scaling problems such as precipitation of calcium carbonate or aluminum silicate are a consequence of carryforward from upsets in causticizing or the lime kiln. Since turpentine underflow and evaporator condensates do contain sulfur compounds, it is expected that scaling due to sodium sulfate may be partially attributed to dirty condensate recycling. However, this problem is normally associated with incomplete reduction in the recovery furnace.

Powerhouse

Surveying various mills across the United States yielded an astounding variety of condensate recycle rates. Twelve mills reported boiler feedwater make-up to be in excess of 60% while two reported make-up of about 35%. The variation in condensate recovery is primarily associated with condensate recycling in liquor evaporation and digesting. It is almost a universal practice among mills to use paper/pulp drying condensates. Therefore, this source does not appreciably affect boiler feedwater make-up due to direct steam heating in bleaching operations. Those mills reporting the poorest rate of condensate recycle employed many of the following:

- o Direct steam digester heating
- o Process application of liquor evaporator clean condensates
- o Little recycle in bleaching
- o Live steam heating of machine wire pit

Since the boiler feedwater make-up represents less than 1000 gal/ton of the freshwater consumption in a typical bleached Kraft process, it is expected that economic incentive for such recycle is almost zero . In fact, many of the newer plants actually have less condensate return than older plants because direct steam heated continuous digesters have captured the market. Because of the high capital and maintenance costs associated with heat exchangers, this trend should continue at newer mills. Other forms of thermal energy savings such as countercurrent bleaching and closed washing and screening offer great thermal savings which will more than compensate for direct steam heating. These energy savings will likely result in less steam required per ton of product thus requiring less freshwater make-up to boiler feedwater even at low condensate return rates.

Economic Constraints

Over the past two years, pulp and paper markets have been weak causing a shortage in available capital for mill improvements. This condition coupled with recent delays in enacting proposed environmental standards has substantially weakened the economic attractiveness of water recycle projects. Only those mills experiencing water shortages or anticipating problems with freshwater supplies in the immediate future have remained active with mill improvements in this area.

The progress of recycle programs in the industry has been further hampered by dramatic increases in energy costs over the past decade. This is especially true for those mills in the northeast that have historically relied heavily on fuel oil. These increases in costs have generally made energy savings projects much more attractive in terms of cost paybacks. Of the 25 mills visited during this study only two were active in large capital water recycle projects, but practically all mills were active in reducing fuel costs.

If energy costs stabilize, as indicated by current trends, and increasing problems occur with the availability of freshwater supply (or quality), it is extremely likely that mill improvements will again be closely associated with increased water recycle. With regard to bleached paper and pulp mills, new technologies in bleaching processes are emerging that not only offer lower chemical and/or energy costs but also lower freshwater consumption. Of notable mention is the emergence of gas phase chlorination or oxygen bleaching. These technologies along with diffusion washing appear to have an excellent future in reducing freshwater requirements for the process by several thousand gallons per ton.[43]

MILLS VISITED WITH EXCEPTIONALLY LOW WATER USE

Mill audits were conducted in an effort to augment published information found on the industry today. Available time and budget limited the visits to 25 mills, therefore a selection process was utilized to visit key mills of exceptionally low specific freshwater usage (freshwater usage per unit of product) in the ten production categories of particular interest. The balance of mill visits consisted of those plants who were average or above average in water use. It is interesting that the information found in directories published on mill conditions did not closely agree with the information obtained from the visits. Generally, the published data reflected more of what can be considered the mill capability in production, steaming rates, water usage, etc., and not actual rates which are reflected by market conditions.

Of the 25 mills visited, 15 were well below industry averages in freshwater usage for their particular production categories. Mills visited with below average water usage consisted of the following production categories of interest:

- Market Bleached Kraft
- Unbleached Kraft
- Alkaline Fine Paper
- BCT Bleached Kraft
- Papergrade Sulfite
- Non-integrated Fine Paper
- Unbleached Kraft Semi-chemical
- Miscellaneous Integrated

Dissolving Kraft and sulfite mills with low water usage were not included due to the inability to schedule the visit. All the mills visited were typical in their production processes with the most notable variance being the conversion of many mills to continuous wood chip digestion which offers a host of benefits over conventional batch processes. No specific correlation could be found however between freshwater use and this since both continuous and batch digestion mills can exhibit low specific freshwater usage. Also, no correlation could be found between regional location and water usage because low water using mills were found in all the regions of heavy pulp and paper activity.

The motivating force for reducing freshwater usage is quite varied but the two main driving forces appear to be economics and availability. Listed below are a number of more specific reasons for water conservation in those mills of below average specific use.

- Low quality freshwater supply (high treatment costs)
- Water usage cost (energy)

- o Municipality waste treatment utilized (high costs)
- o Economics, environmental
- o Municipality freshwater supply (high costs)
- o Environmental constraints
- o Anticipated water shortages (loss of Colorado River allocation)
- o Seasonal freshwater shortages
- o Limited freshwater (permit limitations and complaints from local farmers)

Although most mills visited agreed to the potential economic benefits to higher levels of recycle, few indicated present shortages in availability as a motivating force. Eight mills of average water usage indicated a concern for future availability and almost all of these mills are active in increased recycle programs. Those mills recognizing only the potential economic benefits were generally less active in increased recycle programs because of limited funds for improvements, difficulty in justifying water related projects, or making improvements in areas of greater returns.

All mills that used less than average amounts of water had reached that status by modifications to an older mill design. These 15 mills were all several years old and had improved water recycle through plant modernization. Each of the mills listed a large number of recycle techniques with the additive effect of reduced freshwater withdrawals reaching several million gallons per day in only a few years. Below are listed the more common techniques utilized by these mills to achieve lower water requirements:

1. Recycle vacuum pump effluents.
2. Machine white water recycle within the machine run.
3. Machine white water recycle up the process stream.
4. Installation of high pressure-low volume felt showers.
5. Bleaching effluent recycle.
6. Recycle cooking and liquor evaporation condensates.
7. Wastewaters utilized in cooking liquor preparation.
8. High level clean condensate recycle (low boiler feedwater make-up).
9. Dry woodyard or the utilization of wastewater only in the woodyard.
10. Evaporative cooling used.
11. Low or no freshwater utilized in cooking, brown stock washing, and screening.

The individual recycle techniques in themselves did not offer major reductions in freshwater requirements, but the combination of a large number of these in a single mill helped reduce freshwater needs well below the average. Those mills who operated on notably lower water requirements utilized many recycle techniques which require a lot of management attention to maintain them.

It is also interesting to note that the recycle techniques listed above are applicable to almost every production category. Many mill subprocesses are typical regardless of final product or chemical process. The major division would be in collating integrated mills from nonintegrted ones. All integrated chemical mills operate woodyards, utilize water in cooking liquor preparation, wash the liquors from the cooked pulp, and operate pulp-paper machines. This generic similarity offers water recycle which differ on points of application and chemical constraints. Similarily, bleaching operations were found to be similar in that the process is performed in multiple stages with interval washing, yielding the potential for countercurrent or jumpstage water recycle. Finally, the paper machines were found to be astoundingly similar in the use (or potential use) of white water for recycle, press/vacuum pump recycle, and cooling water recycle.

References - Section IV

1. Marshall, D., et al., "The Relation Between Water Use, Economy and Waste Water Management for Environmental Quality Protection in the Paper Industry", in Proc. of the WWEMA Industrial Pollution Conference and Exposition, Houston, TX, March 30-31, 1973.

2. Matthews, J.E., "Industrial Reuse and Recycle of Waste Water - Literature Review", R.S. Kerr Environmental Research Lab, Ada, OK, December, 1980.

3. Aschoff, A.F., "Water Reuse in Industry, Part 1--Power Generation", Mechanical Engineering, Vol. 95 (4), 1973 (p. 21).

4. Haynes, D.C., "Water Recycling in the Pulp and Paper Industry", TAPPI, Vol. 57 (4), 1974 (p. 4).

5. Gellman, I.E., "The Relation Between Process Water Quality Characteristics and Its Reuse Potential in Fine Paper Mills", Technical Bulletin #287, NCASI, New York, NY, 1976.

6. Casey, J.P., Ed., "Pulp and Paper Chemistry and Chemical Technology", Wiley-Interscience Publishers, Vol. I & II, 1980.

7. Nelson, G.G., et al., TAPPI, Vol. 55 (5), 1972 (p. 133).

8. Gullichsen, J., "Recent Achievements with the Displacement Bleaching Process", TAPPI, Vol. 57 (10), 1974 (p. 111).

9. McHugh, J.P., "White Water Closeup," Presented to TAPPI, June 2, 1978.

10. Springer, A., et al., "The Relation Between Process Water Quality Characteristics and Its Reuse Potential in Non-Integrated Manufacture of Tissue and Toweling", Technical Bulletin #289, NCASI, New York, NY, 1976.

11. Frette, T., "Water Conservation and Fiber Economy", Paper Technology, Vol. 15 (5), 1974 (p. 271-278).

12. Annon, T., TAPPI, Vol. 54, 1971 (p. 1734).

13. L. Rakosh, Pulp and Paper Magazine, Canada, Vol. 75 (3), 1974 (p. 63).

14. "Water and Stock Conservation on Fourdrinier Machines", Summary of Annual Meeting Pres. TAPPI, Vol. 54 (10), 1971, (p. 1734).

15. Honeycutt, "Reuse of White Water on a Bleached Board Fourdrinier Paper Machine", M.S. Thesis, N.C. State University, 1970.

16. M. Priester, "Quality Water - Quality Paper", TAPPI, Vol. 47 (1), 1964 (p. 145).

17. Walden, C., "Toxicity of Pulp and Paper Mill Effluents", TAPPI, Vol. 60, 1977 (p. 122).

18. Aldrich, L., and Jones, R., "White Water Reuse on a Fine Paper Machine", TAPPI, Vol. 56 (3), 1973 (p. 92).

19. Gellman, I., "The Relation Between Process Water Quality Characteristics and Its Reuse Potential in Combination Board Mills", Technical Bulletin #282, NCASI, New York, NY, 1975.

20. Baker, E., "Chlorine Dioxide Proves on Effective Biocide in Alkaline White Water Systems", Pulp and Paper, Vol. 54 (8), 1980 (p. 140).

21. Buckman, S.J., "Water Reuse and Deposits Control", Southern Pulp and Paper Magazine, Vol. 36 (4), 1973 (p. 17).

22. Martin-Lof, S., et al.,"Establishment of a Closed System for the Papermaking Process", TAPPI, Vol. 56 (12), 1973. (p. 121).

23. Wilkinison, J., "A Practical Approach to Water Conservation in a Paper Mill", Pulp and Paper International, 1973.

24. Kazich, R., "Savealls as an Integral Part of Paper Making", Presented to the 5th Annual TCP Meeting, Mexico City, 1965.

25. Velinski, J., "Operational Measures for Reducing the Specific Requirements of Fresh Water by Paper Mills", DAS Paper 26, 1972 (p. 619).

26. Clark, J., et al., "Energy Conservation Research in the Paper and Allied Products Industry, Phase 1", Georgia Institute of Technology Engineering Experiment Station, Final Report, Atlanta, GA, 1979.

27. McCourt, J., "Water Reuse Quality and Practices and Georgia Pacific Toledo Mill", Special Report, NCASI, New York, NY, April 6-7, 1978.

28. Rickles, R.N. and Balakrishnan, S., "By-Product Recovery and Pollution Control." Water and Wastes Engineering, Vol. 6 (9), 1969 (p. E26).

29. Ashler, P.E., H. Norrstrom, and B. Warnquist, "Chlorides in the Kraft Recovery System II. Process and Equipment Aspects on a Closed-Bleached Kraft Mill", Preprinted Proceedings, TAPPI/CAPPA International Pulp Bleaching Conference, Chicago, IL, May 2-6, 1976 (TAPPI, Atlanta, Georgia) (p. 19).

30. J. Isbister, et al , "The Closed Cycle Concept Kraft Mill at the Great Lakes Paper Co., Ltd.", New Technology, August 1978 (p. 23).

31. Histed, J.A. and F.M.A. Nicolle, "Water Reuse and Recycle in D (C) EDED Bleaching", Pulp and Paper Magazine of Canada, Vol. 75 (5), 1974 (p. 69).

32. Nicolle, F.M.A. and J.A. Histed, "Water Reuse from the Bleachery to the Recovery System", Preprinted Proceedings, Air and Stream Improvement Conference, Canadian Pulp and Paper Association, Technical Section, Montreal, Sept. 23-25, 1974 (p. 113).

33. Histed, J.A. and F.M.A. Nicolle, "Water Reuse and Recycle in the CDEHDED Bleach Sequence", TAPPI, Vol. 59 (3), 1976 (p. 75).

34. Rapson W., & Reeve, D., "The Effluent-Free Bleached Kraft Pulp Mill: The Present State of Development", TAPPI, Vol. 56 (9), (p. 112).

35. Reeve, D., et al., "Effluent-Free Bleached Kraft Mill", presented at the International Pulp Bleaching Conference, Chicago, May 1976.

36. R. Brannland, et al., Suensk Paperstidn, Vol. 79, (18), 1976 (p. 591).

37. McDermott, G., "Sources of Wastes from Kraft Pulping and Theoretical Possibilities of Reuse of Condensates", Technical Bullettin #70, NCASI, New York, NY, 1954.

38. Anon, "Pollution Effects of Pulp and Papermill Wastes in Puget Sound, Report on Studies Conducted by Washington State Enforcement Project", in cooperation with the Washington State Pollution Control Commission, March 1967.

39. Kleppe, P., "Survey of Water Utilization and Waste Control Practices in the Southern Pulp and Paper Industry", Water Resources Research Institute, U. of North Carolina, Project A-036-NC, 1970.

40. Hrutfiord, B., et al., "Steam Stripping Odorous Substances from Kraft Effluent Steams", EPA-R2-73-196, April 1973.

41. Bengkuist, S., and E. Foss, "Treatment of Contaminated Condensates in Kraft Pulp Mills", International Congress on Industrial Waste Water, Stockholm, Sweden, Nov. 1970.

42. Smith, H., "Low Operating Costs - A Feature of Thermal Compression Evaporation", TAPPI, Vol. 46 (12) 1963 (p. 182).

43. United States Water Resources Council, "The Nation's Water Resources 1975-2000, Volume 1: Summary," U.S. Government Printing Office, Washington, D.C., 1979.

44. Frye, Russells "NSDES Rules for Industrial Discharges: New Obligations, New Opportunities", Journal of the Water Pollution Control Federation, (Vol. 54 (10), October 1982 (p. 1349).

Section V

THE FEASIBLE EXTENT OF WATER RECYCLE IN EXISTING MILLS

INTRODUCTION

During the mill visits it was observed that most employ recycle/reuse, but the exact process recycle schemes vary from mill to mill. Some plants use recycle waters extensively on brown stock washing while others recycle extensively at the paper/pulp machine. Plants located on water sources which are limited on a seasonal basis recycle more extensively than those that have bountiful water supplies during most of the year. Of course, the level of recycle varies between these two extremes.

In general, recycle strategies depend less on product constraints (pulp quality, for example) than external factors such as economics and availability. The primary motivations stem from effluent limitations and/or fiber loss, with energy and chemical savings being of secondary importance. Recycling benefits are often difficult to quantify in terms of purchased fuel and chemical costs. Those mills that recognize these savings after implementing a recycle scheme may still be unable to quantify the total savings.

Another limiting factor on recycle is the ever present fear that such changes will jeopardize final product quality. The conservative nature of the industry prevailed during the visits as the mills emphasized the importance of the specific qualities of their final products. Process changes are closely scrutinized to assure little or no impact on product quality. Consequently, process changes must offer strong economic incentives to be accepted by management. The quality control groups at most mills exert a significant amount of influence, making it difficult to obtain funding for water recycle programs even if cost effectiveness is quantified. Often, a strong motivating force such as problems meeting effluent permits or production loss due to freshwater nonavailability must be present before quality control personnel yield to pressures to implement additional water recycle programs.

Historically, the industry has been composed of followers instead of leaders in reducing effluents and controlling freshwater intake. Legislative action plus external factors like water availability have been the most influential in causing changes in water usage practices. The most notable exception is where market pressures have been effective in controlling energy consumption. Here, very high returns on investment have brought about significant changes in processing techniques.

Again it should be emphasized that all recycle schemes discussed are not universally adaptable or even cost effective, but they are scenarios which should be considered closely since they can be utilized in typical mills. Computer simulations of the various pulp/paper mill processes along with support from the literature indicate the recycle schemes discussed in this section are technically feasible for a wide variety of mills. Since cost savings were not regularly offered to support the schemes, this information needs further study on a mill-by-mill basis. However, some mills have already employed these schemes indicating their potential cost effectiveness. Thus, the technical and economic feasibility is supported by existing mill experience of the various recycle schemes.

PULP/PAPER MACHINE

The machine white water system is perhaps the most widely studied area for recycle because of its large requirement for high quality water and its impact on so many production/quality components. These components range from machine tonnage capability to felt life. Therefore, increased recycle from common practice requires intense study to review factors such as:

- Machine operation and production
- Wire and felt life
- Sheet drainage and chemical retention
- Press efficiency
- Equipment corrosion/scaling
- Final product quality

Of all of these factors which may enter into the cost of a project, usually only two factors - chemical and thermal costs - enter into the savings. This is because increases in productivity and decreases in maintenance are not usually quantified for their savings potential when mills justify instituting a recycle project. Many times, even the cost of water use is neglected in savings justification, yet recent studies are changing this approach.

Since the paper/pulp machine represents one of the larger consumers of energy within a mill, it is realistic that it should be a prime target for energy conservation. Table V-1 below shows how this area compares in energy consumption with other areas within a typical Kraft mill.

Since 32% of the average total energy consumed is in paper/pulp drying, it is reasonable that a similar fraction of total plant fuel consumption must be consumed for this operation. Other paper production processes like sulfite and nonintegrated mills show an even larger fraction of energy being consumed in the machine room.

During the 1950's and 1960's it became popular to operate machine white water systems at elevated temperatures. Normal temperatures of 90-100°F were increased to about 140°F by a variety of methods. Increases in stock temperature offered a host of benefits including higher drainage on the fourdrinier and improved efficiency in the press section, thus higher machine productivity.[2] Even mills that utilize stock additives like rosin, size, and extenders have found satisfactory performance at the higher temperatures.[3]

Table V-1. PRIME ENERGY USERS IN INTEGRATED PULP AND PAPER MILLS[1]

Process	Energy Usage Range MMBtu/adt*	Avg. % Total Energy
Pulping	8.6 to 12.0	34%
Recovery	6.9 to 7.6	23%
Paper/Pulp Drying	4.0 to 10.0	32%
Other	2.4 to 3.7	11%
Total	21.9 to 33.3**	100%

*Air Dried Tonnage
**Average Energy Used (First Half 1978): 31.4 MMBtu/adt

Unfortunately, many mills utilize live steam addition to the wire pit which has proven costly with the significant energy cost increases of the 1970's. Many mills continue today to heat with live steam or utilize hot water inefficiently for stock heating. By increased white water recycle and/or the employment of low volume felt showers, the thermal needs for this can be significantly reduced.[4] For example, a typical northern Kraft mill may wish to control machine white water temperature at 140°F to maintain a given production rate of 600 TPD. The machine may typically require about 6.5 million gal/day of 70°F freshwater for felt showers, wire showers, vacuum pump sealing, trim, etc. Since the stock enters the process at the desired machine stock temperature (140°F), the wire pit heating is principally required to heat the freshwater entering the machine. If this is accomplished at 60% efficiency by steam costing $2.00 per 1000 lb., annual costs are $4.6 million.

A high level of white water recycle will eliminate this heat requirement. Thermal input from the stock in the last bleaching stage (or unbleached decker) can offset the cooling effect of introducing excessive amounts of freshwater into the process. The same machine could also enjoy a savings in pH control. Since the white water pH is controlled to approximately 4.5, chlorine/acid savings are possible in eliminating the need to reduce the freshwater pH from 7 to the desired 4.5.

Recycle of machine white water to augment freshwater requirements may be accomplished either internal to a subprocess or external to other subprocesses within the mill as shown in Figures IV-3, IV-4, IV-5 and IV-6. Internal recycle may be accomplished by several combinations as shown on a simplified machine process diagram (Figure IV-9). Here, effluents from the press section return to the white water system via the saveall with numerous shower and dilution streams coming from the clarified white water chest to various points of application. The only point where white water is rarely substituted for freshwater is the felt conditioning showers. This is because the very small orifices on these high pressure showers easily plugs. However, three mills surveyed use white water for a fraction of their felt shower water requirements.

Hypothetically it is possible to eliminate all freshwater requirements on the machine room because the stock coming from the final bleach washer or screen room decker has a higher moisture content than the stock leaving the press section. In this scenario, excess white water will be generated even though no freshwater is introduced to the machine. This excess water could then be utilized as shower water in the final bleach washer or screen room decker. This is not feasible however, because of the buildup in concentration of dissolved and suspended substances in the machine white water system. Excessive levels of these substances will render uncontrolled scale/pitch build-up, corrosion, excessive temperature, poor wire/felt performance, and biological growth. The actual level of recycle is thus limited and is specific for various machine configurations, pulp/paper feedstock, and final product.

BLEACH PLANT

The bleach plant, because it is the second greatest freshwater consumer in a typical bleached Kraft mill, has also been studied extensively for water recycle. The most extensive recycle scheme under evaluation today was developed by Rapson[8] in 1967 as shown in Figure V-1. It includes full countercurrent washing with all bleaching effluents utilized in some part of the various mill processes. The major technical limitations for such a system include corrosion in the bleach plant, salt buildup in the liquor system, and initial cost. However, because of the thermal and chemical requirements as well as the high level of waste effluents, such a system holds promise as being economically justifiable.

Modifying an existing mill to accommodate the Rapson process would require a significant change of mill processes and an upgrading of equipment materials. However, the utilization of the Rapson process, in part, may prove cost effective in a large number of mills. Table V-2 lists a number of potential recycle schemes and their freshwater savings potential that might possibly find widespread application in mills. All of these innovations cannot be applied to the same mill, but several in combination are possible. Potential benefits include:

- Less BOD_5 discharge
- Less effluent volume
- Reduction in bleaching steam requirements
- Reduction in bleaching chemical requirements
- Elimination of pitch buildup in unbleached stock piping
- Less caustic make-up to liquor system
- Higher energy content of black liquor

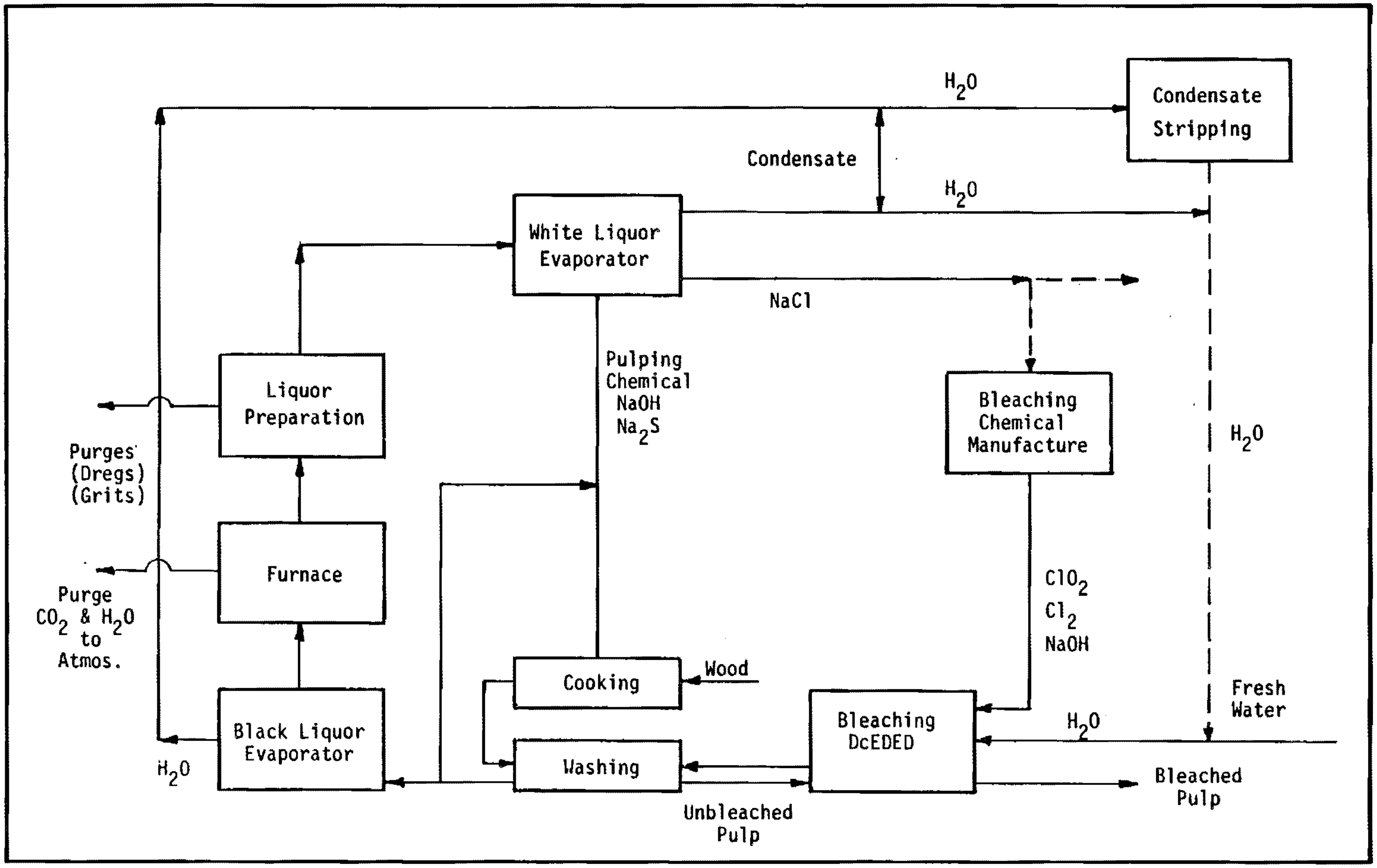


Figure V-1. FLOWSHEET OF THE CLOSED-CYCLE BLEACHED KRAFT PULP MILL

Table V-2. POTENTIAL BLEACH PLANT RECYCLE SCHEMES

Process Innovation	Freshwater Savings Potential (gal/ADT)
1. Utilize chlorination effluent for brown stock dilution[9]	1,100
2. Convert to high density gas phase chlorination or oxygen bleaching[10,16]	2,000
3. Utilize bleach effluent for brown stock washing[8,11]	2,000
4. Utilize machine white prior to low pH bleaching stages[12]	5,000
5. Utilize some countercurrent washing and/or jump stage washing[13]	20,000
6. Utilize stripped dirty condensates on washer showers[14]	5,000
7. Convert to displacement bleaching[15]	10,000

Rapson[8] has indicated that high levels of recycle in bleaching usually cause a net increase in bleach chemical requirements. However, significant levels of recycle are deemed possible before this happens in many mills today because most existing mills are using volumes of washwater that are significantly higher than utilized in a fully closed, countercurrent process.

Pulp bleaching processes account for a notable amount of energy consumption. A typical five stage (CEDED) bleach plant for a medium size Kraft mill (1000 TPD) can consume in excess of 100,000 lb/hr of steam. Using the aforementioned value of $2 per 1000 lb of steam results in an annual cost of $1.7 million per year. In addition, the process typically requires almost $10 million per year in bleaching chemicals. These costs are certainly of a magnitude to justify close scrutiny for potential savings.

Several major innovations in bleaching technology have been proven commercially in the past two decades including:

- Countercurrent washing
- Diffusion washers
- High density first stage bleaching
- Equipment materials upgrades
- Computerized bleach control
- Dynamic bleaching

These improvements in the bleaching process have not only contributed to reductions in energy and chemical costs but also have yielded fiber savings, effluent reductions, and savings in freshwater requirements. In general, savings from such innovations have come from bleach stage effluent recycle and reductions in dilution water requirements. Unfortunately, such innovations in bleaching processes almost always require intense capital expenditures for material upgrades in existing equipment and/or major modification of existing processes. A potential savings exists for innovations but cost effectiveness cannot be generalized due to the heavy capital requirements and variety of process specifics for each mill.

Innovative bleach plants are commonly found in mills built within the last five years, yet there exist a number of potential process upgrades in practically all existing plants. Economics for existing process upgrades on a major scale have yet to be proven attractive. As environmental regulations require more sophisticated waste treatment, many mills will likely consider the reduction of bleaching effluents (both volume and BOD_5) through internal recycle and process modifications instead of the traditional methods of enlarging existing waste treatment facilities. A completely closed cycle mill has been incorporated at the Great Lakes Paper Company, Thunder Bay, Ontario.[6] The additional capital costs for the closed process are offset by eliminating the need of a secondary biological waste treatment. But, the overall savings is realized by the ongoing costs of the treatment system that is not required due to process water recycle. Other mills recently constructed in the United States and Europe also show significant reductions in total freshwater requirements. Many of these have been achieved in conjunction with reduced energy and chemical costs plus reductions in effluent. These systems incorporate technologies that are not at their zenith, such as at Thunder Bay, but which demonstrate the economic and technological attractiveness of improved water recycle or reduction of dilution requirements.

Significant reductions in freshwater requirements and corresponding effluents are achievable at limited capital costs. Two notable scenarios which are being practiced to a limited degree include brown stock dilution utilizing chlorinated effluent and utilization of paper machine effluents and/or seal box effluent for selected washer showers. Both process innovations require a minimum of technical complexity and capital investment. One mill visited reported a savings of 85,000 lb/hr of steam, 3600 gal/min of freshwater, and 3 ton/day of caustic soda through an extensive recycle of seal box effluents. This approach could account for an annual savings in excess of $3 million per year. Another report[11] in which a mill utilized a completely countercurrent (split system) bleach plant resulted in reductions of steam to one fourth that of a typical bleach plant and freshwater requirements less than 7000 gal/ton. Capital costs for such process modifications are high due primarily to the extensive use of 317 stainless steel and titanium for protection against excessive chloride corrosion.

DIGESTING, WASHING, AND SCREENING

With all of the diverse sources of recycle water applications cited in the literature, it is not an overstatement to conclude that all brown stock washing and screening requirements could be met with a least one of these streams. In fact, all of the mills visited utilized some recycle water for at least part of their washing and screening water requirements. Unfortunately, only ten mills utilized recycle water for 100% of these needs; and many plants utilized clean condensates for brown stock washing, which is a terribly high quality stream for this application.

In general, brown stock washwaters have few quality requirements to satisfactorily meet this need. The following three constraints for washwater are indicated to be the primary constituents for satisfactory recycle application:[12]

1. High temperature (125°F) for maximum washing efficiency but not so high to cause flashing in the drip leg.

2. Satisfactory pH to keep black liquor pH above 11 to prevent lignin precipitation in evaporators.

3. Low enough concentrations of silica, aluminum, or calcium compounds to avoid excessive evaporation fouling or foaming.

Many wastewater streams can meet these constraints in a typical mill. These streams include blow gas condensates, cooling water for blow gas condenser, turpentine decanter, turpentine condenser water, evaporator condensates, and evaporator barometric effluents.[14] Thus, reuse is possible without forcing significant plant modifications and creating the problems with black liquor evaporation.

One of the biggest concerns with Kraft processes commonly expressed by mill spokespersons was that through heavy recycle, increased concentrations of unwanted substances would build up in the liquor cycle. The problem of chemical (and thermal) buildup is real and may very well result in negative impacts on mill processes and/or pulp quality. Mill spokespersons of processes utilizing recycle waters do not support this, however; component concentrations of most concern are maintained at a manageable level in all recycle applications with the exception of the most extensive scenarios or in plants with unique constraints.

Many plants have also overcome this problem by converting to brown stock screening systems which require very little water, either recycled or fresh. This system performs all or most of the screening operation prior to brown stock washing as opposed to the more traditional reverse of this procedure as shown in Figure III-9. Usually this approach involves the utilization of continuous chip digestion. With this procedure of screening in black liquor, reductions in recycled water requirements to under 2000 gal/ton are quite common. Future reductions in average water requirements are expected to be achieved by widespread use of the techniques described above. Older processes which are inherently large freshwater users will simply be retired under pressures of environmental consciousness and energy efficiency.

In conclusion, most plants employing typical levels of recycle should experience few problems in concentration buildup of unwanted substances. Because most mills have a unique set of outside influences such as freshwater quality and effluent constraints, a stepwise institution of increased recycle should enable plant engineers to identify the point at which increased recycle will render negative operational effects.

CAUSTICIZING

Causticizing includes the entire lime cycle and white liquor preparation process in all Kraft processes. It is similar to digesting, washing, and screening in that freshwater quality constraints are minimal. Processes such as white liquor dilution, green liquor make-up, lime mud washing, dregs washing, and lime kiln venturi scrubbing systems typically account for over 1000 gal/ton of a plant's freshwater consumption. However, many mills find it cost effective to utilize water streams such as dirty (and clean) condensates, washing and screening decker effluent, and bleach extraction effluents to satisfactorily meet these freshwater requirements.[14]

Of those Kraft mills visited, five utilized some form of wastewater for part of the causticizing processes. Unfortunately, wastewater reuse for this application was limited to one or two processes per mill, yet technical limitations for greater reuse were few. The authors anticipate complete elimination of freshwater use here by 2000 with waste treatment costs being the primary driving force.

POWERHOUSE AND LIQUOR RECOVERY

Powerhouse and liquor recovery operations (including liquor evaporation) account for approximately 1500 gal/ton direct water usage in a typical Kraft mill with consumption to a lesser extent for other processes. This flow includes boiler feedwater make-up and cooling water for smelt spouts, air compressors, etc. Indirect cooling requirements for liquor evaporator condensers may account for up to 15,000 gal/ton.

As a general practice, most mills utilize indirect cooling waters as part of the freshwater intake for mill processes. This offers an improved thermal efficiency by heating freshwater inputs a little closer to processing temperatures. Particularly in the warmer regions, this has led to excessive freshwater consumption during the summer months as water supply temperatures increase to as much as 90°F yielding an increase in cooling water volume to the evaporator condensers. A seasonal change in existing water recycle efficiency is frequently encountered where heavy summer freshwater consumption for evaporator condensers is subsequently used in other mill processes thereby lowering recycle rates. Mills whose water supply is affected by summer droughts have improved process water management by returning condenser waters to rivers or steams and/or employing evaporative cooling to combat excessive process thermal buildup during summer months. Mills who operate in cooler climates are less prone to seasonal consumption variations. Unfortunately, modifications of water cycles and/or the installation of evaporative coolers is not economically justifiable except for those mills with a limited water supply.

Aside from evaporator cooling, condensate recycle notably affects freshwater requirements. Most Kraft mills recycle approximately 50% of their condensate with the balance being lost in direct steam heating processes, leakage, and application for other processes. Many modern processes today cook stock by direct steam injection (see Figure V-2) because this approach reduces digestion process capital costs significantly. White liquor dilution due to direct steam heating is compensated by increased liquor strength rendering comparable black liquor evaporation costs with that of conventional indirect cooking. Many of those mills utilizing indirect steam digestion showed no greater condensate recycle as most digester clean steam condensates are applied to brown stock washing.

Future reduction in freshwater use in the powerhouse and liquor recovery is expected to be minimal with the exception of those mills changing to evaporative cooling for the black liquor evaporators. Motivations for this lie in areas already mentioned such as excessive process water temperatures in the summer and seasonal shortages in freshwater availability.

PUMP SEAL WATER

Pump seal water can account for almost 4,000 gal/ton in some mills. Many are actively pursuing the use of mechanical seals which eliminate water requirements and maintenance. Due to the poor cost effectiveness of retrofitting with mechanical seals in many mills and the lack of satisfactory overall service on such units, it is believed that the use of wastewater streams, such as clarified machine white water or even tertiary treated wastewater, may be a more cost effective approach. Problems with thermal buildup and corrosion are the major technical problems affecting implementation. Casey[12] has noted a variety of schemes for reducing freshwater consumption in vacuum pumps while meeting temperature and corrosion constraints. Mill visits did not identify anyone pursuing this approach, yet the literature[17] suggests it is attractive.

Conversion of existing water sealed vacuum pumps to mechanically sealed configurations such as a lobe type is another approach to reduce seal water requirements. This approach is somewhat limited perhaps only to new pump installations since most plant spokesmen indicated that the recycle of existing pump seal waters appears the more economically attractive alternative.

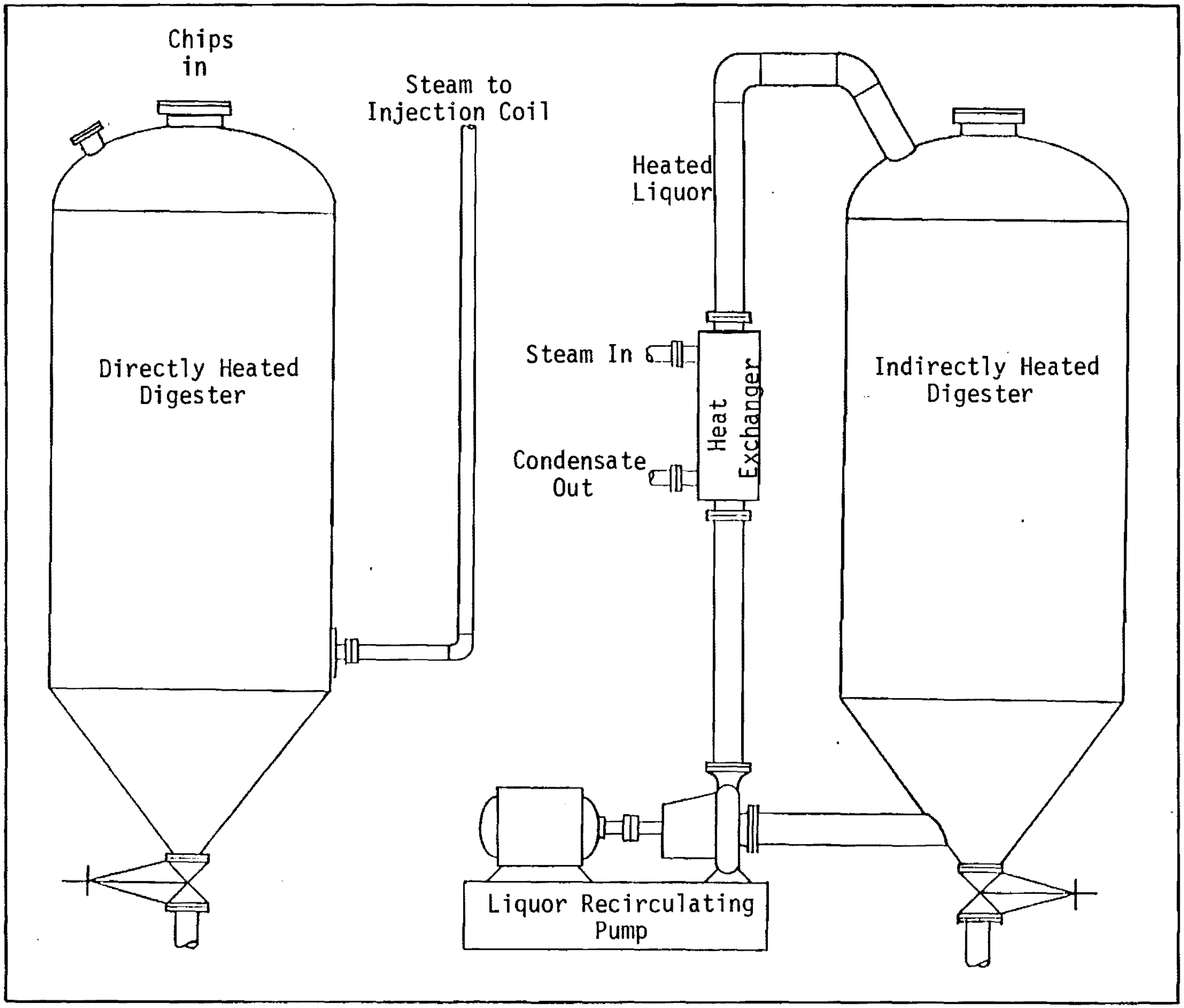


Figure V-2. COMPARISON OF DIRECTLY VS. INDIRECTLY HEATED DIGESTERS

INTERMITTENT LOSSES

Casey[12] has indicated that unsteady state mill conditions can result in excessive water usage by as much as 25% that of steady state requirements. A spokesman from one of the mills visited supported this by indicating his belief that over one million gpd of freshwater could be accounted for by spills and wash-up activity in his mill.

Elimination of these losses is practically impossible due to process upsets caused by equipment failure. It is possible, however, to minimize these losses through improved process control and the employment of wastewater for wash hoses. Improved process control by computerization is being utilized throughout mills for better management and reduction of losses. Computerized process control systems were reaching new levels of sophistication in almost every mill visited as management strived to improve mill productivity and reduce chemical, thermal, and fiber losses. Such systems will certainly better control intermittent losses.

Utilization of wastewater streams for washing up should be a consideration in every mill, since the quality constraints for such waters are few yet the savings can be substantial. It is difficult to quantify such savings but considering that a wash hose requires approximately 30 gal/min and that a typical mill commonly has from 5 to 10 hoses running at any one time, the potential savings may well be over a half million gallons per day.

COMPUTER SIMULATION OF SELECTED RECYCLE OPTIONS

Computer simulation for a generic fourdrinier paper machine system was conducted to establish index figures of how much freshwater is required to allow a machine to operate satisfactorily. Also, the fundamental barriers to increased recycle were identified.

Water Quality Constraints

Based on a similar study using a computer model of the paper process, three water quality constraints were chosen to be examined:

- o Dissolved solids concentration
- o Suspended solids concentration
- o Thermal energy buildup[20]

These three stream characteristics have been cited as the most critical in assuring product quality and proper operation of the process, in addition to being conducive to simulation with GEMS. Below is a brief discussion of how each of these fundamental characteristics affects machine processes.

Dissolved Solids Concentration

Total dissolved solids concentration (TDS) consists of various chemical components of wood such as carbohydrates, lignin, and resins[21]. Cited as being a more serious problem in mill operation than suspended solids concentration[22], the upper operating limit on dissolved solids at the headbox is in the range of 3000 to 4000 ppm with a lowest possible operating level of approximately 1000 ppm. The primary factory influencing concentration throughout the process seems to be the retention of TDS on the wire.

The effect of decreased water consumption on TDS levels has been well documented. One report[19] illustrated increases in TDS levels of up to 200% with extreme attempts at decreasing freshwater consumption. The relationship reported is exponential with the concentration of some components increasing by a factor of 10 at 90% recycle.

The principal problem associated with high dissolved solids content is increased corrosion. This problem manifests itself in numerous ways. Not solely dependent on dissolved solids concentration, the problem is associated with essentially the entire mill. The tolerance to corrosion is highly specific to the process point in question. Large diameter, thick walled pipes are somewhat insensitive, whereas high speed equipment such as pumps may completely fail due to localized corrosion in relatively short periods.[23] One report noted the effect of water with a pH of 4.5 and dissolved solids content of approximately 12 lbs/1000 gallons on a Nash vacuum pump. Deterioration was reported to have progressed steadily throughout a one-year test period until it was eroded beyond repair. Nash has since developed lobe purges to bleed the corrosive material from the pump rim.[22]

A National Council of the Pulp and Paper Industry for Air and Stream Improvement report[24] noted that high headbox concentrations of dissolved solids affected different forms of corrosion at varying rates. Pitting corrosion seemed to pose the least problem, while crevice and deposit corrosion showed a lower tolerance for dissolved solids. Operation at high solids levels was not possible without the use of 316L stainless steel in place of the alternative 304 stainless.

Another report presents the interesting possibility that corrosion due to TDS may in fact be an erosion problem manifested by abrasive materials precipitated out of solution during periods of low water usage. The possible precipitates were found, however, to be incapable of producing the observed level of abrasion.[22]

Suspended Solids Concentration

Suspended solids consist of fiber fragments and fillers.[25] Operating conditions at the headbox have been observed with total suspended solids concentrations (TSS) as high as 6000 ppm. This value was taken to be the upper limit for unbleached Kraft production in the options executed in this study.

Scale deposits result from crystallization, precipitation, and coagulation of nonresinous substances.[22] The formation of scale has commonly been associated with increased suspended solids concentration. These deposits can accumulate throughout the process: plugging screens, filters and wires; restricting flow through pumps and piping; and, to some degree, reducing heat transfer.[25] Such concentrations will inevitably reduce product quality.

Several methods are practiced to control scaling. Among the more successful are the injection of dispersing agents into the process, velocity control, improved clarification, and the use of sequestering agents.[23]

Perhaps the most serious problem caused by increased suspended solids concentration is the plugging of shower heads used at various points in the machine process. Described in more detail later as a process option, suspended solids (unless filtered or clarified by a suitable means) will plug the standard-size orifices used on wire or felt showers. This problem almost eliminates recycling process effluent through the felt showers today.[26]

Suspended solids can aggravate drainage problems on the wire and, in turn, reduce product quality. Fines and fillers tend to exhibit a first pass retention of approximately 50% on average. This value has shown little dependence on the level of water consumption. Experiments have shown that process effluent TSS concentration is roughly independent of the level of reuse in the mill. It then follows that solids will be exited with the product at higher concentrations, and thus reduce quality.[21]

Thermal Buildup

Temperature plays a major role in proper machine operation. There are incentives for operating a mill at both extremes of the temperature spectrum. A warmer process stream is favored to increase drainage from the wire and thereby allow increases in production rates. For most mills this operating temperature is about 140°F.

High operating temperatures have produced other benefits as well. Increases in the felt shower water temperature to around 140°F aided in felt conditioning and increased drying capacity.[27] High temperatures have also significantly reduced bacterial growth, and hence scaling problems. The primary benefit from higher temperatures comes from decreases in energy costs for drying. Two mills in one study reported steam savings as great as $0.2 per ton of production.[24]

Operating a warm process with increased production must be balanced against the problems caused in the vacuum pumps. Flashing of the seal water can occur at temperatures above 130°F. Such a condition reduces pump efficiency and at temperatures above 140°F makes operation impossible. The optimum temperature for the vacuum seal system is around 125°F, depending to some extent on the particular application. Similar problems have been noted in gland sealing waters.

One report noted that increases in temperature have a very definite effect upon sizing.[22] Stock temperatures as high as 150°F could conceivably be reached under high levels of recycle. At such temperatures, deterioration in sizing can occur with holding times as low as 30 minutes. After two hours, all sizing is virtually destroyed. The problem can be alleviated by adding sizing as close to the headbox as possible.

In short, the high and low end temperature constraints require vigilant control throughout the process.

Computer Simulation Options

In the computer optimization runs, the recycle alternatives were restricted to those considered economically feasible for a mill in current operation. Various technologies exist which could conceivably reduce freshwater consumption to exceedingly low levels. Due to the prohibitive capital cost of modifications on existing mills, such technologies cannot be feasibly utilized.

The basepoint from which computer simulation began was a consumption rate of 5600 gallons of water per ton of product, the lowest commercial intake found. Although this figure represents only the consumption of the paper formation process, the vast majority of the data in the literature is similarly tabulated. By far the largest consumer in the Kraft process, the paper-making process is particularly conducive to modification (as well as modeling) because it is largely a mechanical process, as opposed to the chemically sensitive bleaching and pulping processes. The basepoint for process constraints was chosen to essentially mirror existing process characteristics of water consumption.

The water quality of the effluent leaving the machine headbox was chosen as the point of determination for process constraint violation for two reasons:

1. All stock must pass through this point in the process before exiting through the mechanical presses. Hence water characteristics in the headbox have a profound effect upon product quality.

2. An overwhelming majority of white water is formed as a result of drainage from the paper sheet forming out of the headbox.

Hence the ability of the water to be recycled is directly dependent upon the quality of the headbox effluent.[24]

One approximation was made concerning the retention of dissolved solids across the wire. Components were assumed to split exactly as the total white water flow is separated. In practice, individual components are separated in varying degrees ranging from 3% to 97% retention. A median value of 50% was chosen for the retention of suspended components.[20]

Four options were analyzed on the baseline model:

Option 1. Reduce the volume of freshwater to the felt showers
Option 2. Recycle white water to gland seals and machine showers
Option 3. Recycle white water for vacuum pump sealing
Option 4. Recycle white water into unbleached screening and bleaching

Below is a summary of each.

<u>Option 1</u>

The felt conditioning showers currently represent the single largest user of water in the paper formation process and are probably capable of the largest decrease in consumption.

The press felts accompany the wet paper mat from the couch roll at the end of the fourdrinier through the mechanical press section. The felt conditioning showers serve to saturate the felt and loosen any entrained particles. The shower water then serves as a medium to trap and transport the particles which the showers and other equipment have loosened. These particles are then removed from the press felts by the vacuum box. Typical conventional shower pressure is maintained at 75 psig, with a water temperature of 140°F; approximately 2100 gallons per ton of product are required.[12]

Two basic proposals have been attempted in practice to reduce consumption by the felt showers:

1. The recycle of mill process effluent or white water.
2. The use of low-volume, high-pressure intermittent showers.

The less successful of these is the recycle of white water. In any attempt to recycle white water, the primary concern is the impurities which increase in concentration as more freshwater is replaced. For the use of such water in the felt showers, the plugging of shower head orifices has been the prevalent problem cited. Specifically, residual stock entrained in the recycle streams will obstruct orifices of sizes smaller than 0.05" in diameter. Orifices larger than this diameter have been used with limited success when assisted by prefiltration with 60-mesh screens. Regarding this problem, it should be noted that the size of the individual particles is more of a limitation than the concentration of the components.[28] Hence, GEMS is not applicable for this facet of the suspended solids constraint.

Partial success in usage of process water upon one set of machine felt showers has been reported,[29] but a particularly effective saveall system was in use. Suspended solids content in the clarified white water was below 30 ppm, well below the values reported as typical.[12,24] Others[23] have found serious problems in plugging due to high suspended solids content, but obtained much better results when the white water was first driven through a microscreen. They concluded that felt life is independent of the quantity of water used (and hence the orifice size) as long as the felt remains saturated.

The other method of decreasing consumption by the felt showers is through the use of low-volume, high-pressure intermittent showers. Savings can be as great as 94%[12] of that consumed in normal low-pressure, continuous showers. In addition to the benefit of decreasing the freshwater intake, the volumetric load on the saveall is reduced.[30] Although requiring freshwater for the remaining 5-10% of flow, the saving is impressive and desirable in view of the technical problems associated with recycle onto the felts as discussed above. One manufacturer reported successful use of 500 psig showers with no loss of felt life.[31]

The high-pressure shower configuration is uncomplicated, yet the felts must be made of stronger, synthetic material with the ability to withstand the high-pressure shower jets. The high pressure showers are then used typically for three to four hours per day, at 20 to 30 minute intervals.[26] However, a low-volume, conventional shower may also be necessary in some cases to achieve complete felt conditioning.[12]

In the simulations attempted, the high-pressure shower configuration was modeled by incrementally decreasing the freshwater flow into the felt conditioning to determine its effect upon the headbox stream characteristics. Purely for academic completion, the flow was eliminated completely in the last execution to obtain the results for this limiting case.

Option 2

Gland packing is used in centrifugal pumps to ensure the air-tight separation of the impeller chamber from the environment. Gland water in turn lubricates and cools this packing.[32] A typical mill has approximately 25 such pumps, using an average of 1250 gallons per ton of product mostly used in moving stock or white water.

Two strategies have been recommended for reducing consumption by the pump seals. One involves the replacement of the packed seals with mechanical shaft seals, while the other utilizes the recycle of white water. The former of these requires no water input and may be used in most sealing applications. There have been some reports on the success in using mechanical seals for all freshwater, white water, and effluent pumps. Maintenance costs here are also reduced through this modification, with a service life exceeding two years. On those pumps still requiring the gland sealing technique, consumption can be reduced by implementing more stringent controls on freshwater input. One report[26] proposed using a low-pressure header with precisely sized orifice plates delivering only the manufacturer's specified flow. It has been estimated that by using mechanical seals, water consumption may be reduced by approximately 90%, to 149 gpt.[12]

A problem has been cited in the use of mechanical seals. Apparently, installing such seals to pump impeller shafts requires very precise tolerances. Hence maintenance costs are higher, and downtime is increased. None of the mills visited utilize mechanical seals at this time.

The latter method of reducing pump seal consumption involves the recycle of white water into standard gland packing. This method was simulated with the GEMS model because of its wide use.

Some difficulties have been associated with recycle into the pump seals. They primarily involve those problems associated with any increase in recycled water, i.e., elevated operating temperatures, scaling on equipment, line plugging, and accelerated corrosion. Several strategies have been implemented to correct these problems. Some utilize temperature control on the seal water, flushing valves to prevent line plugging, the use of stainless steel in lines where applicable, and mesh strainers to remove suspended solids.[24]

Option 3

Closure of the vacuum pump system has been widely investigated. The principal constraint upon closure is the temperature rise that the process stream undergoes across each pump.

Vacuum pumps are responsible for pulling the excess dilution water off the stock as it is transported across the fourdrinier and presses. Consistency is increased from 0.5% to approximately 18% as the stock reaches the press felts. Simple gravity decanting is not sufficient to achieve this level of separation.

The vacuum pumps make use of water to seal the vacuum produced by the pump impeller. Typical water sealed vacuum systems can account for 2000 gal/ton of freshwater use, offering substantial savings in freshwater requirements.

Several strategies to reduce freshwater consumption by the vacuum pumps have been proposed and, in many cases, implemented. Because of the thermal sensitivity in maintaining an adequate vacuum, proper temperature control is critical. Increased closure inevitably produces intensifications in both the solids concentration and temperature. High temperatures reduce the vacuum due to both the larger volume occupied by saturated air, and the increase in flashing of vacuum pump sealing water. Maximum temperature tolerance is variable depending on the level of vacuum required and vacuum loss tolerated. For some cases, water temperatures as high as 140°F are permissible.[33]

Other strategies have involved the separation of the vacuum pump seal water system and recycle of the pump effluents. Due to the thermal constraints described above, system closure must be under precise temperature control. One proposal in operation uses a cooling tower to reduce the pump effluent temperature to its input value.[22] Partial closure is attained by mixing that quantity of freshwater (approximately 10% of total volume at 125°F) with the volume of process effluent necessary to attain proper input temperature.

The recycle of process effluent presents the third option for decreasing consumption by the vacuum pump system. Of the variety of options available here, recycle of saveall clarified white water was chosen for modeling on GEMS. Other problems with recycle, in addition to increased temperature, involve the low pH of white water leading to corrosion, and the buildup of scale in the pump interior. The Nash Company has presented requirements for white water quality for recycle, with dissolved solids levels limited to 500 ppm. In practice, this level has been found to be overly restrictive with concentrations several times higher employed.

The white water recycle option was selected for simulation with the GEMS model for two reasons: it has been demonstrated as a workable alternative in mill practice; and it was well suited for direct application in the GEMS model with both the recycle stream and the original vacuum input well defined.

Option 4

Recycle of white water into the brown stock washers is a particularly complicated scheme because any contamination recycled upstream affects the entire paper mill water system. This phenomenon is known as "carryforward".[24]

The brown stock washing system is responsible for removing the spent cooking chemicals entrained in the cooked fiber. Failure to do so effectively results in loss of recyclable cooking chemicals, in addition to countless problems associated with chemical reactions later in the process.

Under present mill operation, the principal sources of displacement washing water used are fresh hot water and condensates from digestion and liquor recovery. In this study, the liquor recovery system was not examined. Hence the white water recycle in washing is not discussed. Numerous problems result from increased white water usage on the brown stock washers. Large increases in dissolved solids concentration have been observed due to this practice, in one case increasing headbox concentration by 1500 ppm. One mill reported intolerable problems with increased evaporative scaling after only minor attempts at white water recycle were made.[24] Another went so far as to call any recycle beyond the point of unbleached storage impractical.[34] However, most mills still operate unbleached stock screening systems with substantial requirements of freshwater. These freshwater requirements can be reduced or eliminated either by screening closeup, with heavy internal recycle, or machine white water recycle, or a combination of both. Ability to utilize machine white water here or elsewhere depends on the white water chemical composition, temperature, and availability. At least ten mills visited either used completely closed screening systems or used at least some recycled machine white water. This alternative was selected for simulation with the GEMS model.

Other processes can be used to reduce the consumption of freshwater in brown stock screening. The most practical of these is the use of an effective control system to ensure that only the minimum freshwater necessary is consumed. Other technologies using a diffusion based washing process have been installed in experimental operations.[19]

Dilution of broke stock input to the paper mill (approximately 35% of total production) is also achieved through recycle of white water. The same source is used for dilution of high density flow from the brown stock decker. This practice has become so common that it cannot be called a modification. Nonetheless, it does contribute to lower consumption of freshwater.

Application of machine white water in pulp bleaching systems is also heavily dependent on white water chemical composition, temperature, and availability. Those mills who input large amounts of starches, rosins, and extenders on the paper machine find recycle for bleaching limited to the final washer stage. Three mills visited utilize significant amounts of white water in the bleaching process. Since this application is quite mill specific, computer modeling is limited to the final bleaching stage.

The options simulated in this work by no means address all possibilities for reducing mill water consumption. Alternatives have been presented, however, which address over 70% of total mill water input.

CASES CONSIDERED

The four options described were executed individually and in combination to ascertain the effect of the possible interactions within the paper mill. Specifically, options 1 through 4 were each run individually, followed by options 1 & 2, 1 & 3, and 2 & 3 executed in combination. Options 1, 2, and 3 were then individually executed with 50% recycle into the brown stock screening and bleaching (Option 4) in order to examine the possible interactions with the additional carryforward. (This last sequence was executed because some level of brown stock wash water recycle was found to be ubiquitous in mill practice, whereas the other options were more selectively utilized). These options, and combinations thereof, resulted in a total of ten cases examined. Below is a summary of the ten recycle optimizations that were simulated:

Case	Recycle Optimization
1	Option 1: Reduce volume of freshwater to felt showers
2	Option 2: Recycle white water to gland seals and machine showers
3	Option 3: Recycle white water to vacuum pumps
4	Option 4: Recycle white water to unbleached screening and bleaching
5	Option 1 and Option 2 combined
6	Option 1 and Option 3 combined
7	Option 2 and Option 3 combined
8	Option 1 and Option 4 combined (50% recycle to screening and bleaching)
9	Option 2 and Option 4 combined (50% recycle to screening and bleaching)
10	Option 3 and Option 4 combined (50% recycle to screening and bleaching)

Three plots were generated for each case. In all but one case, the independent variable was the mill freshwater consumption; in Option 4, the freshwater input to the washers was measured separately from the mill system. For each case the effect of decreased water consumption upon both dissolved and suspended solids levels at the headbox, and thermal buildup were depicted. Thermal problems were illustrated by measuring the steam (in tons/hr of 50 psig steam) necessary to heat the process flow (stream 107) to the headbox operating temperature of 140°F.

Assumptions

A conservative approach was used in obtaining the proper basepoint conditions at the headbox. These levels were generated on the GEMS computer model by careful adjustment of various equipment blocks and input streams. The basepoint was selected largely through the data found in the literature, specifically values listed in the NCASI Report #339.[24] These values were further substantiated by data from the unbleached Kraft mill that the model was loosely based upon. To some extent, the precise point of departure for examination was found subjectively. There is a range of approximately 300 ppm from which optimization could legitimately have begun for both solids components examined; a similar tolerance for temperature exists. This somewhat imprecise range illustrates the lack of any firm definition of water quality in the pulp and paper industry. The conclusions presented should be noted with these considerations in mind.

The basepoint conditions were obtained through the best determination of operating conditions for a 5400 gpt mill. The conditions indicated were:

- o Dissolved solids concentrations of 2700 ppm
- o Suspended solids concentration of 4500 ppm
- o Mill operating temperature of 140°F

Individual Options

Case 1

The reduction of water onto the felts (Option 1) served to raise solids levels throughout the process and slightly raise the temperature of the process flow. Figure V-3 shows the effect of decreased felt water upon the dissolved solids concentrations at the headbox. Beginning at the basepoint level (i.e., 2700 ppm), the level of solids rises inversely, with a concentration of 3250 ppm in the limiting case of no felt shower flow (i.e, machine freshwater consumption of 3750 gpt). In actuality, a minimum shower flow of approximately 200 gpt (i.e., mill consumption of 3550 gpt) is necessary for operation of high-pressure felt showers, which corresponds to a dissolved solids level of 3100 ppm. The inverse behavior of the curve suggests that current mill practice has reduced water consumption to the point of inflection, approximately 5300 gpt, beyond which point increases in dissolved solids become more prevalent for each gallon of water saved.

The nature of the headbox water supply may explain the inverse behavior of the dissolved solids curve. Unlike the suspended solids, no mill operation selectively separates the dissolved solids. Therefore, they tend to be particularly susceptible to decreases in water level. The headbox water loop is, in effect, an almost closed system with respect to dissolved solids. Hence this component tends to be nonlinear with respect to decreases in mill consumption. This behavior is seen in almost every other option analyzed which is external to the headbox water loop (i.e., Options 1,2, and 4).

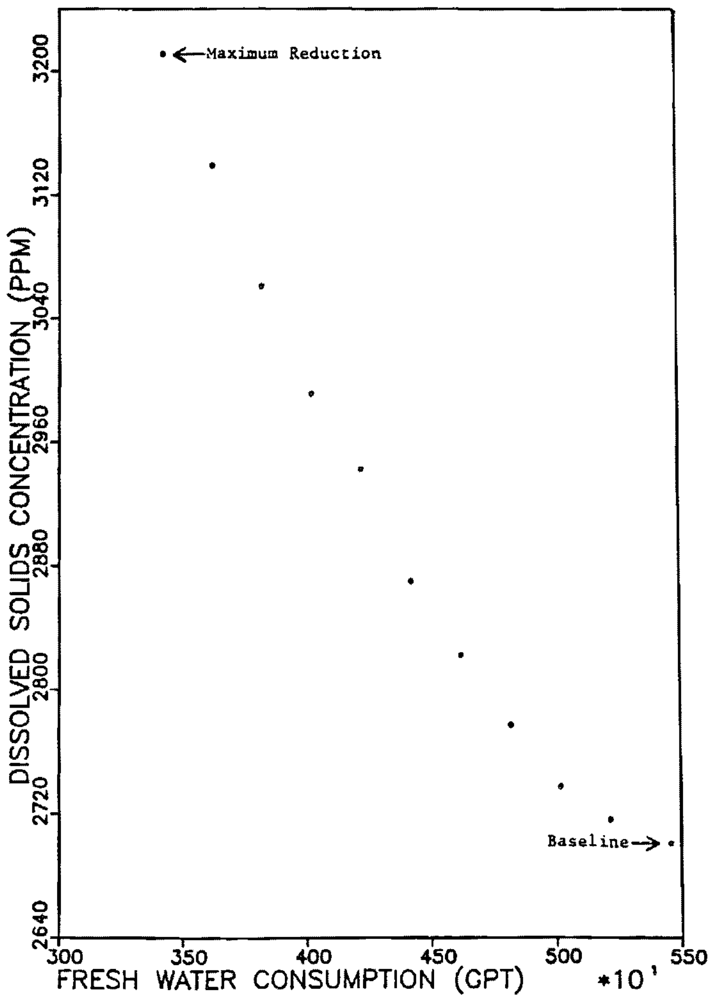


Figure V-3. DISSOLVED SOLIDS BEHAVIOR AT THE HEADBOX AT REDUCED VOLUME INTO THE FELT SHOWERS, OPTION 1

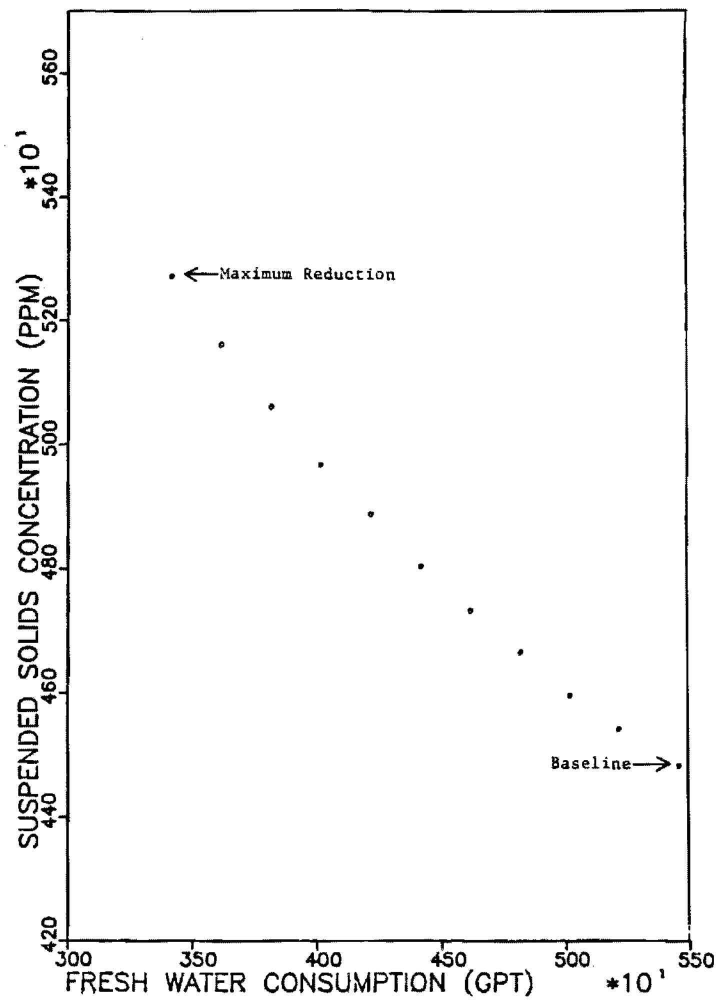


Figure V-4. SUSPENDED SOLIDS BEHAVIOR AT THE HEADBOX AT REDUCED VOLUME INTO THE FELT SHOWERS, OPTION 1

The suspended solids concentration for Option 1 (Figure V-4) is a nearly linear function of the freshwater consumption, undoubtedly due to the "purge" that results from the wire and saveall. With a 50% retention value of suspended solids across the wire, along with the even higher 92% value across the saveall, a large fraction exits from the headbox water circuit, thus allowing for a much lower dependence upon freshwater consumption.

The steam consumption curve for Option 1 (Figure V-5) is a linear function of the temperature into the paper mill. Because the throughput of the process flow is controlled by dilution requirements, the only variable affecting the steam consumed is the temperature of the stock flow that enters the steaming process. In the case of this option, the steam savings are relatively trivial, approximately 2%. This savings is small because the water flow being reduced (i.e., the felt shower water) enters the process flow at a temperature of 129°F, which is only slightly below the process temperature of 140°F.

Case 2

Option 2, recycle to the pump gland seals and machine showers, yields results very similar to those of Option 1. The primary physical difference between the two is that Option 2 involves the reroute of an effluent stream, whereas Option 1 involves the simple reduction of a stream flow. It is significant that both of these options have been executed with at least part of the stream outside of the headbox water circuit, allowing for the similarity in the solids curves for the two cases.

The effect upon dissolved solids concentration (Figure V-6) is the same inverse behavior described in Option 1, but with a somewhat lower peak concentration at 100% recycle. (The maximum level reached in Option 1 was 3250 ppm, versus 2950 ppm in this case). Because the volume of reduction in Option 1 is larger than in this case, the higher peak in the first case (3200 ppm) is to be expected. The behavior of the two curves is virtually identical for the ranges of consumption common to both.

The behavior of the suspended solids (Figure V-7) is affected by the same factors influencing the dissolved solids levels. The recycle of white water into the headbox loop tends to increase the concentration of suspended solids throughout the process, primarily by the linear addition of solids through the recycle stream, but compounded by the effect that higher headbox concentrations have upon the white water. This effect is less prevalent than in the case of the dissolved solids because of the larger purge of suspended solids from the headbox circuit. Dissolved solids concentration in the filtered white water rose 5% more than did the suspended solids level.

The effect of recycle into the gland seals on the amount of steam consumed is substantial and not unexpected in that 77°F freshwater

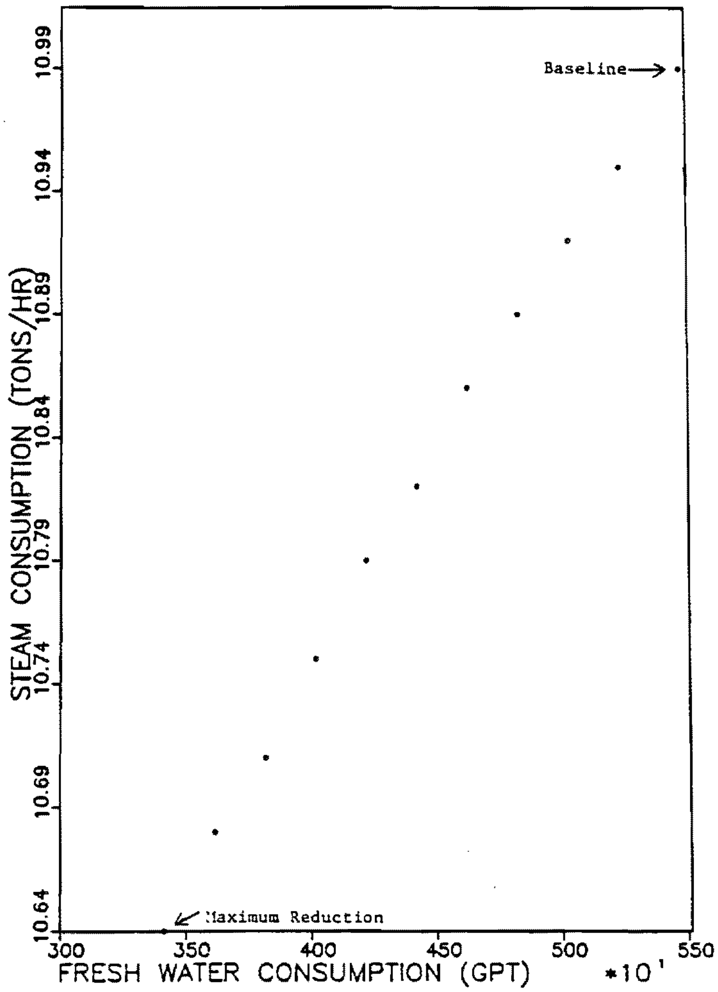


Figure V-5. STEAM CONSUMPTION FOR PROPER WIRE TEMPERATURE AT REDUCED VOLUME INTO THE FELT SHOWERS, OPTION 1

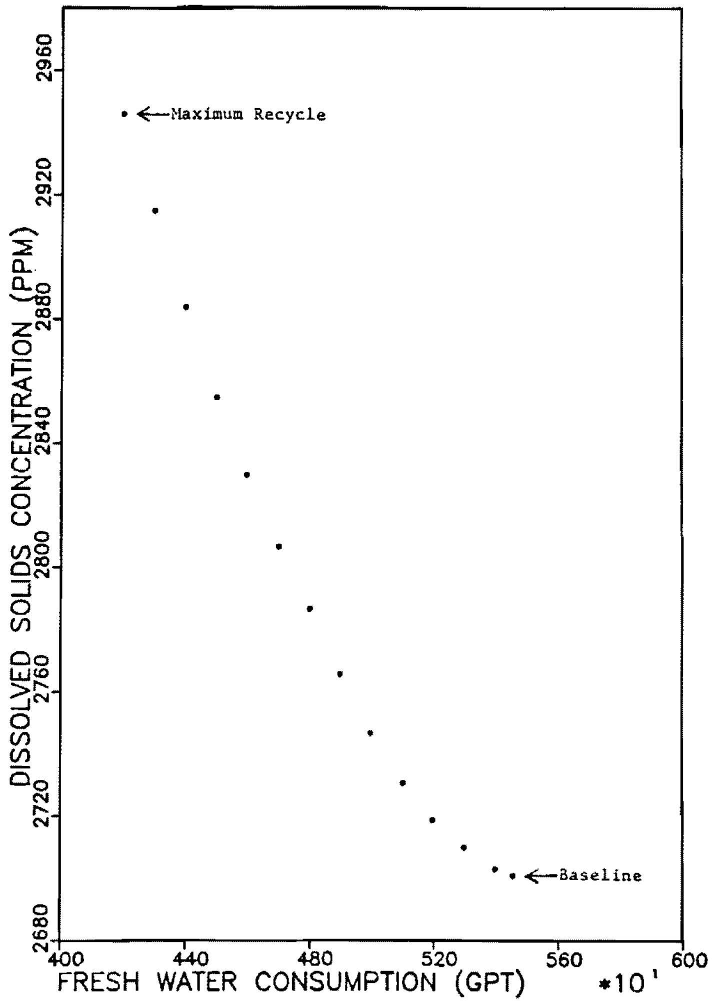


Figure V-6. DISSOLVED SOLIDS BEHAVIOR AT THE HEADBOX WITH RECYCLE INTO THE GLAND SEALS, OPTION 2

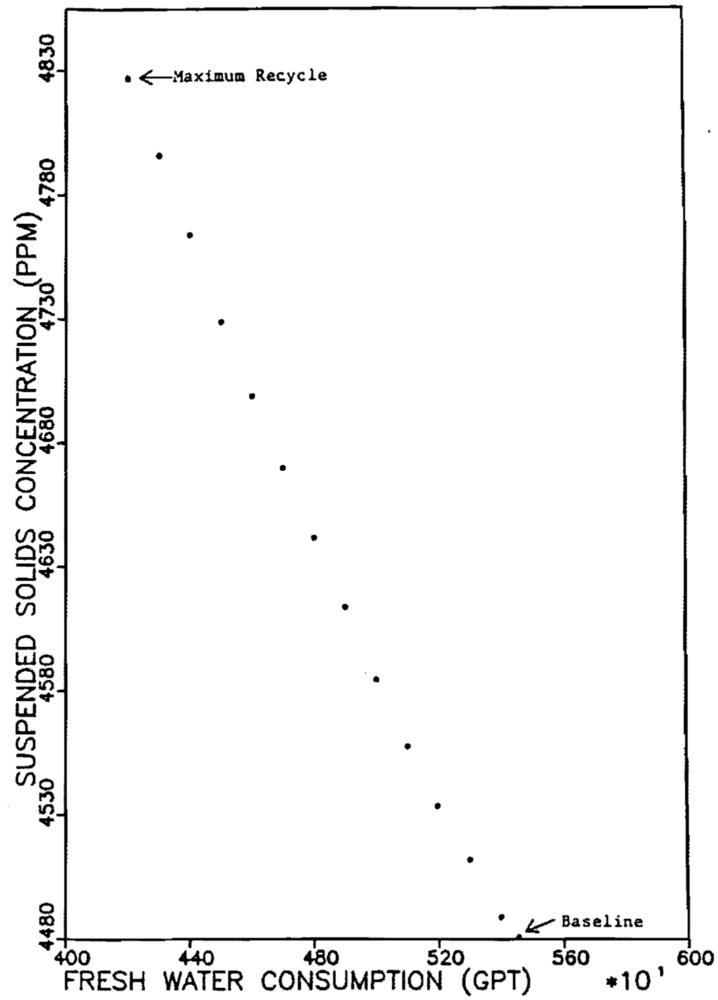


Figure V-7. SUSPENDED SOLIDS BEHAVIOR AT THE HEADBOX WITH RECYCLE INTO THE GLAND SEALS, OPTION 2 was replaced by 131°F white water (Figure V-8). A 4°F temperature change in the input stream to the paper mill reduced steam consumption by 95%. This reduction is logical because only a 6°F rise in stream temperature was necessary in the base case. The behavior of the curve is linear, reflecting the direct dependence of the steam consumption upon input stream temperature.

Case 3

Option 3, the recycle of white water into the vacuum pumps for sealing purposes, is different from the previous two options for reasons other than point of entry. In this case, recycle of white water is input directly into the headbox circuit, thus imposing a nearly linear dependence upon the volume of mill consumption for the dissolved and suspended solids levels.

Although showing more data scatter than in the previous cases, the dissolved solids concentration is linearly dependent upon the level of water consumption (Figure V-9). The magnitude of the increase is greater than in the previous cases, probably because no dissolved components leave the headbox loop, except those that are entrained with the product and, to a lesser extent, those exiting with the wire drainage. (Most of the drainage flow is recycled for dilution at the headbox). This option is probably the least desirable of all the individual options for this reason. Dissolved solids levels in the limiting case of total recycle approach 3500 ppm, exceeding operating levels in less tolerant mills. In contrast, the case of total recycle into the gland seals produced a maximum headbox concentration of only 2950 ppm. It should be noted, however, that the total volume of recycle was one-third smaller in Option 2 than in Option 3. However, even by using the final consumption rate of the gland seal flow as the point of comparison (4150 gpt), the dissolved solids concentration for Option 3 exceeds Option 2 by 400 ppm. The same holds true in the case of Option 1 when compared to Option 3, with a difference of over 450 ppm at the same level of consumption. Extreme care would be necessary in attempting the Option 3 recycle scenario.

The suspended solids level behavior (Figure V-10) mirrors that of the gland seal curve. Apparently because of the purging factor of the suspended solids, its behavior is more uniform throughout the process.

The steam consumption for this option declined as expected and, as in every case examined, in a linear fashion (Figure V-11). The total temperature change of the process across the range of recycle into the vacuum pumps was less than 0.2°F. Hence the total impact upon steam consumption was very small, in this case approximately 0.3 tons per hour.

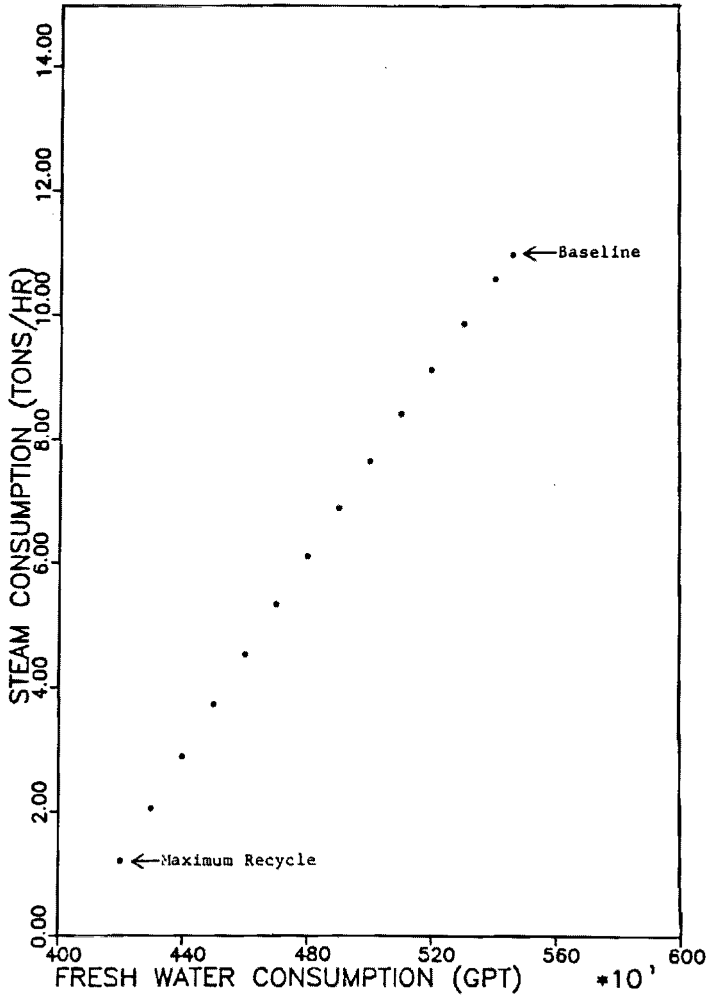


Figure V-8. STEAM CONSUMPTION FOR PROPER WIRE TEMPERATURE WITH RECYCLE INTO THE GLAND SEALS, OPTION 2

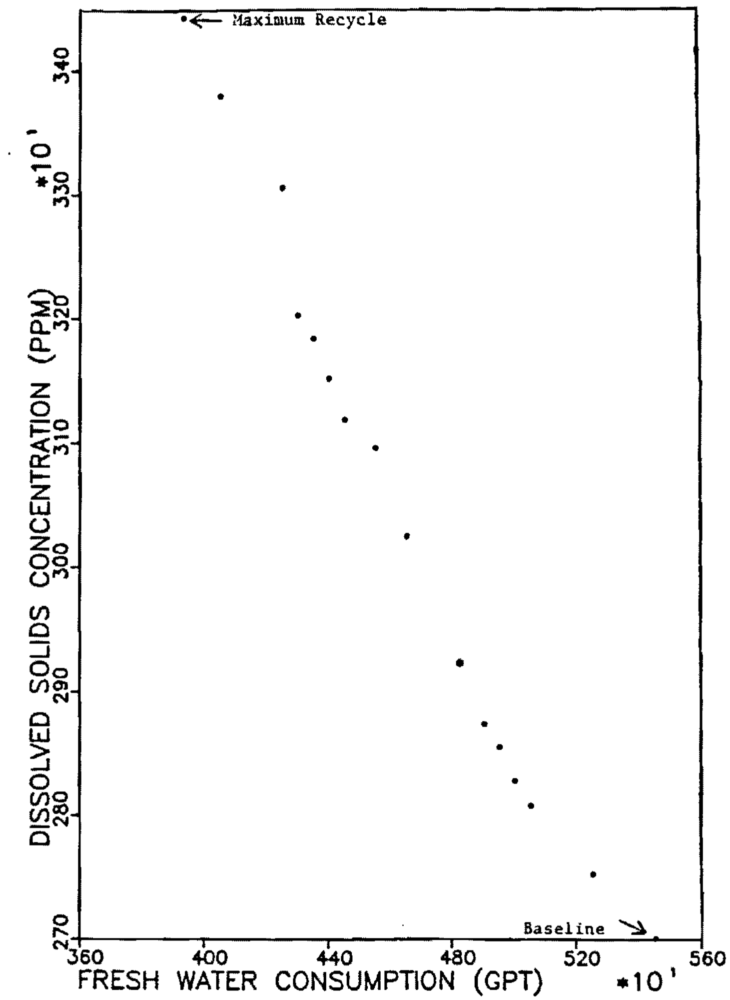


Figure V-9. DISSOLVED SOLIDS BEHAVIOR AT THE HEADBOX WITH RECYCLE INTO THE VACUUM PUMPS, OPTION 3

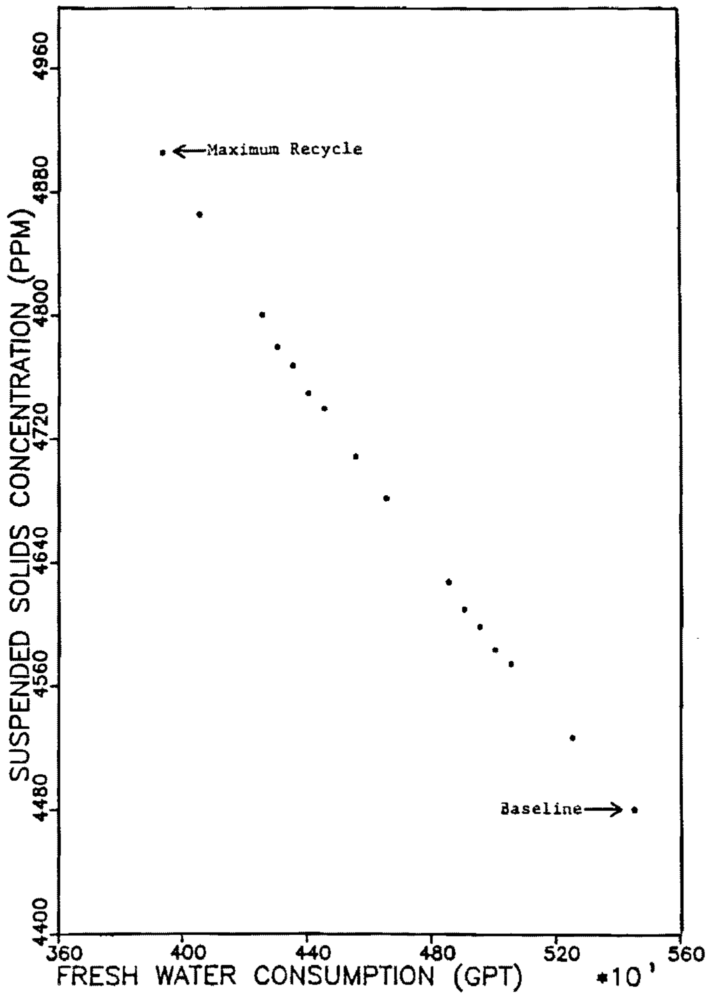


Figure V-10. SUSPENDED SOLIDS BEHAVIOR AT THE HEADBOX WITH RECYCLE INTO THE VACUUM PUMPS, OPTION 3

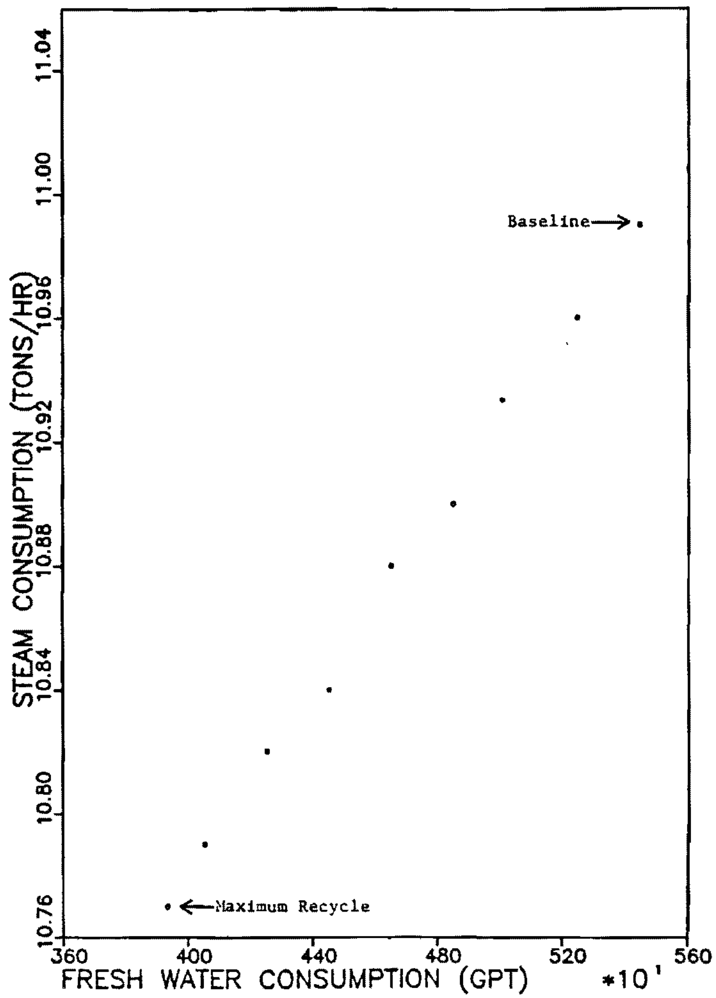


Figure V-11. STEAM CONSUMPTION FOR PROPER WIRE TEMPERATURE WITH RECYCLE INTO THE VACUUM PUMPS, OPTION 3

Case 4

The recycle of white water to the screen room or bleach plant (Option 4) is a unique recycle proposal in that the conditions of the process stream leaving the last decker directly affect the quality of the product and the purity of the white water. This, in effect, determines whether further recycle is possible. As mentioned earlier, this phenomenon is known as carryforward.

The effect of this option upon headbox water quality is most similar to that of Option 1. This is to be expected because the recycle is external to the headbox water circuit and is directly affected by the effluent leaving the press section, as in Option 1. Indeed, over 30% of the white water is composed of the press effluent. The dissolved solids curve (Figure V-12) again exhibits inverse behavior, although to a less pronounced extent than in Options 1 and 2. This illustrates that the feed into the brown stock flow is largely independent of the change in conditions downstream.

This point is made even clearer by the behavior of the suspended solids concentrations at the headbox (Figure V-13). The effect of recycle onto the brown stock screen room and decker is almost perfectly linear, with any compounding effect diluted by the high retention of the wire and even higher efficiency of the saveall.

Steam consumption in this case (Figure V-14) increases in contrast to the behavior of the previous three cases. This behavior is the result of the white water entering the washers at 131°F, considerably lower than the 149°F heated freshwater used originally. This leads to a misinterpretation of mill steam usage because the temperature needed for the original freshwater input must also be obtained through indirect heating, though at some point external to the model.

Summary of Cases 1, 2, 3, and 4

Clearly, sizable reductions in water consumption are feasible. Of the four single options analyzed, the most promising is Option 2, the recycle of white water into the pump gland seals. Even at total recycle, the highest dissolved solids concentration reached was 2900 ppm, below even the most pessimistic reports of constraint violations. The suspended solids rise was also manageable, with the maximum level reaching approximately 4800 ppm. Although steam consumption dropped precipitously, this is not necessarily a favorable development, as thermal buildup could easily become intolerable under slightly warmer operating conditions.

Unfortunately, Option 2 is modeled with the least accuracy of the four individual options considered. Although portrayed as a single stream input, the gland sealing water is, in fact, a

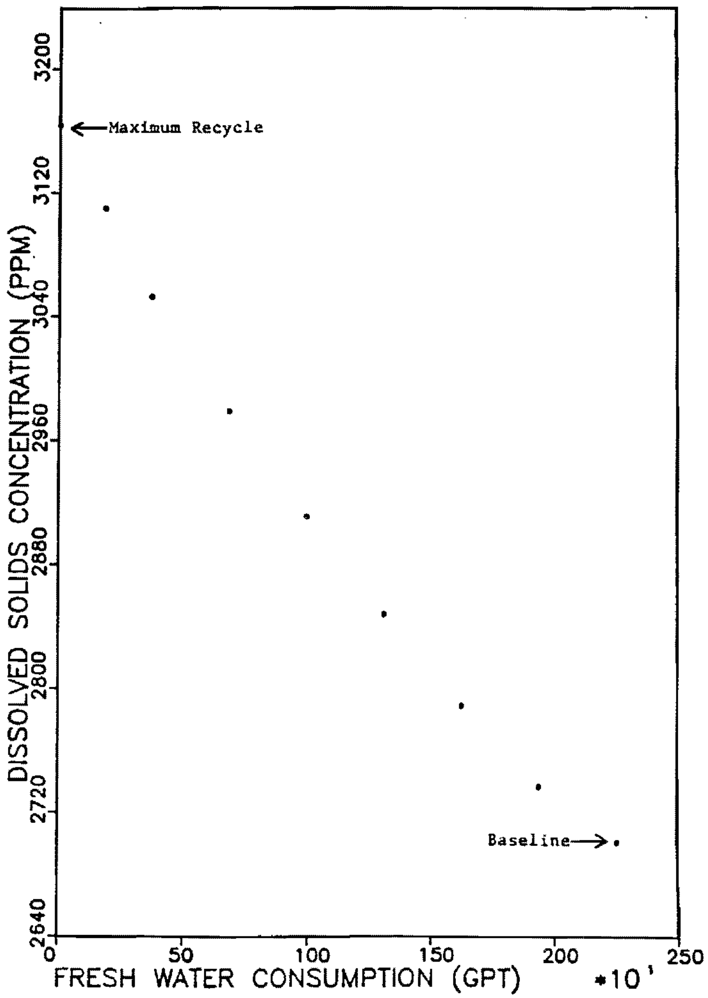


Figure V-12. DISSOLVED SOLIDS BEHAVIOR AT THE HEADBOX WITH RECYCLE INTO THE BROWN STOCK WASHERS, OPTION 4

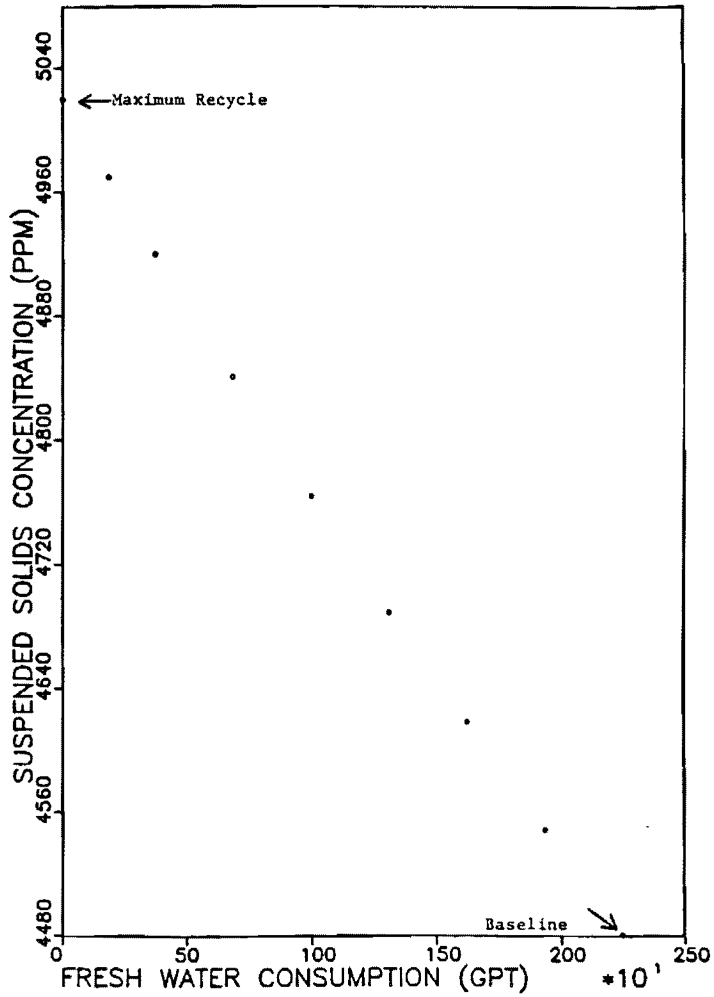


Figure V-13. SUSPENDED SOLIDS BEHAVIOR AT THE HEADBOX WITH RECYCLE INTO THE BROWN STOCK WASHERS, OPTION 4

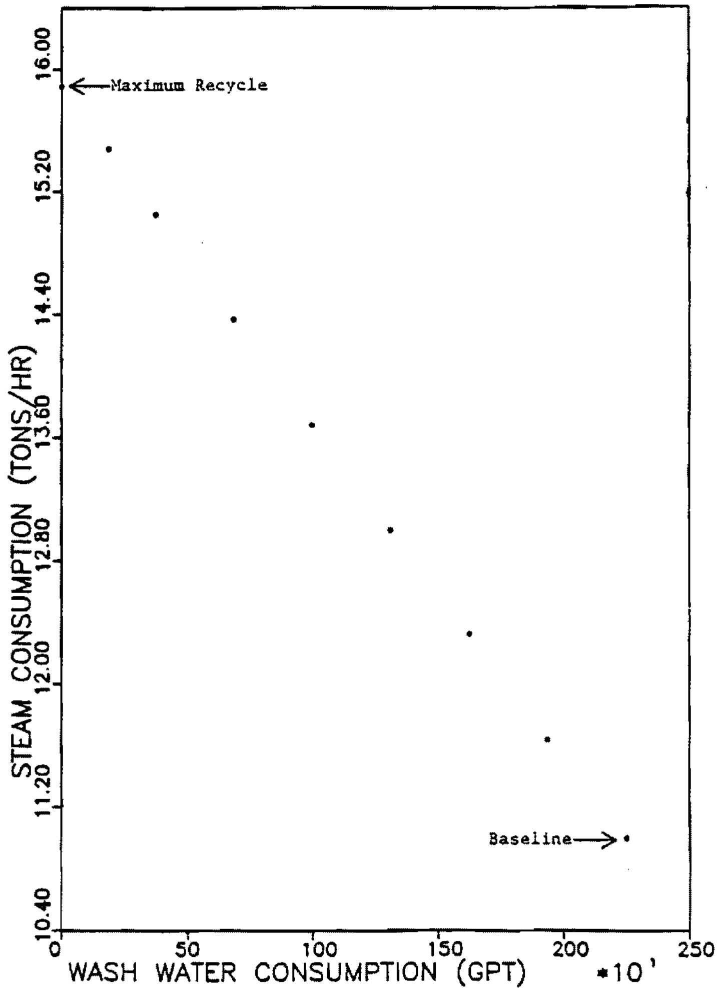


Figure V-14. STEAM CONSUMPTION FOR PROPER WIRE TEMPERATURE WITH RECYCLE INTO THE BROWN STOCK WASHERS, OPTION 4 conglomeration of many minor flows distributed throughout the paper mill and concentrated near the press effluent.

It appears that recycle into the vacuum pumps presents serious problems, as the dissolved solids concentration increases by 25%, to over 3400 ppm, an area in which operational problems have been noted. Similar increases were noted in the suspended solids concentration, although the maximum level did not approach operational limits, peaking at 4900 ppm.

Combinations of Options

The results of combining options into single runs presented behavior which, in most cases, was characterized by simple addition of the behavior of the individual options. The options for each run were executed sequentially, not simultaneously. The most obvious discontinuity was observed in the consumption of steam for all three combinations. The point of transition between recycle options is noted on each curve.

Case 5

For the case of recycle to the gland seals after incremental decreases in volume into the felt showers, the dissolved solids and suspended solids curves are continous, as should be expected, because of the nearly identical point in the process they affect. A dissolved solids concentration of 4000 ppm is reached at maximum reduction of these two streams (Figure V-15), the highest operating limit reported in the literature. Similar behavior is noted for the suspended solids concentration (Figure V-16), again peaking at the highest operating levels reported[24], approximately 6000 ppm. These two options cannot be executed in combination at low consumption levels without damage to product quality.

Steam consumption for this combination registers a negative value at maximum reduction (approximately 2200 gpt), with a cooling load of -1.56 tons/hr needed to maintain process temperature at 60°C (Figure V-17). Obviously, the upper limit on temperature was reached, with the negative value representing the amount of heat that must be removed in order to maintain the proper process temperature.

Based strictly upon the data generated for this case, freshwater consumption as low as 2400 gpt seems possible, but a more conservative figure of 2800 gpt would restrict the dissolved solids level to 3500 ppm.

Case 6

Results of Options 1 and 3 executed in combination are shown in Figures V-18 through V-20. The results were somewhat similar to the previous case with some additional discontinuity present in the dissolved solids behavior (Figure V-18); this is perhaps due

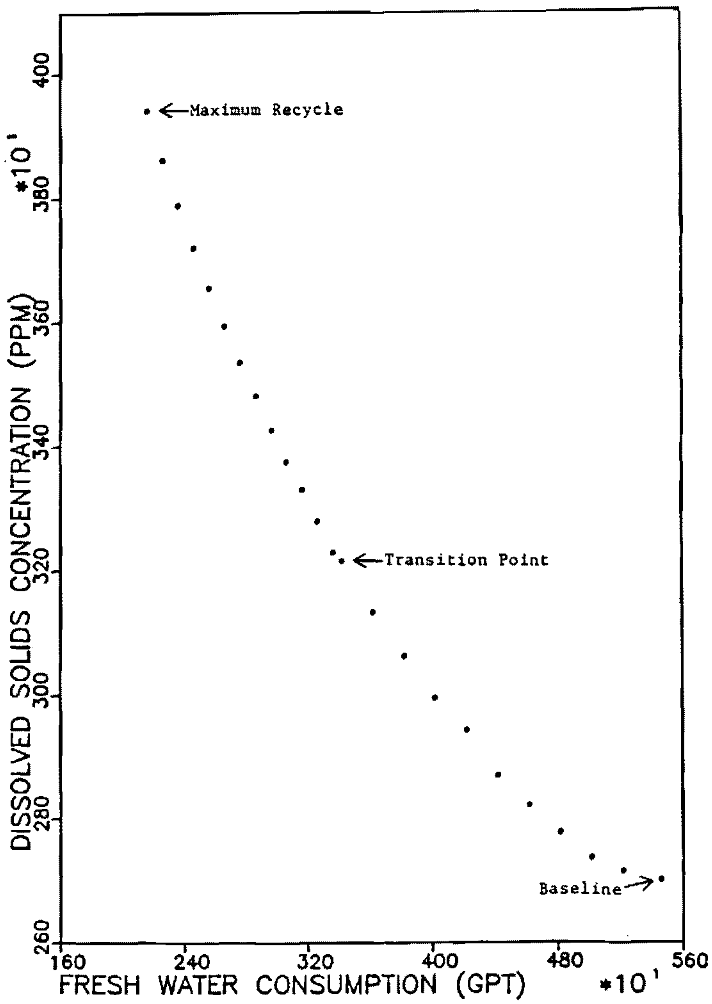


Figure V-15. DISSOLVED SOLIDS BEHAVIOR AT THE HEADBOX, OPTIONS 1 & 2

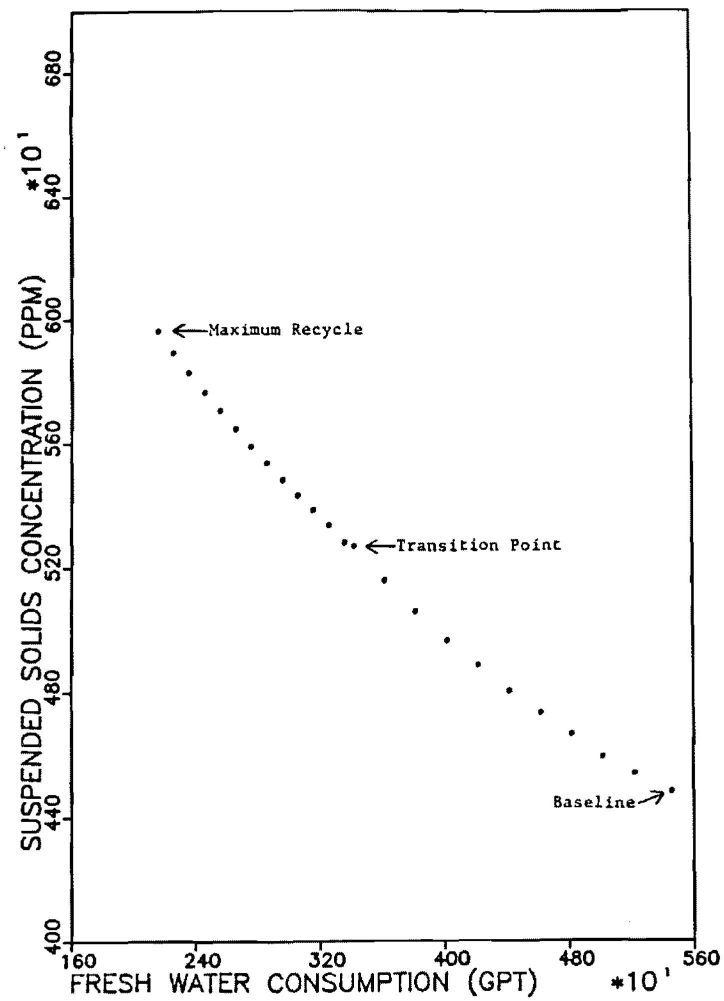


Figure V-16. SUSPENDED SOLIDS BEHAVIOR AT THE HEADBOX, OPTIONS 1 & 2

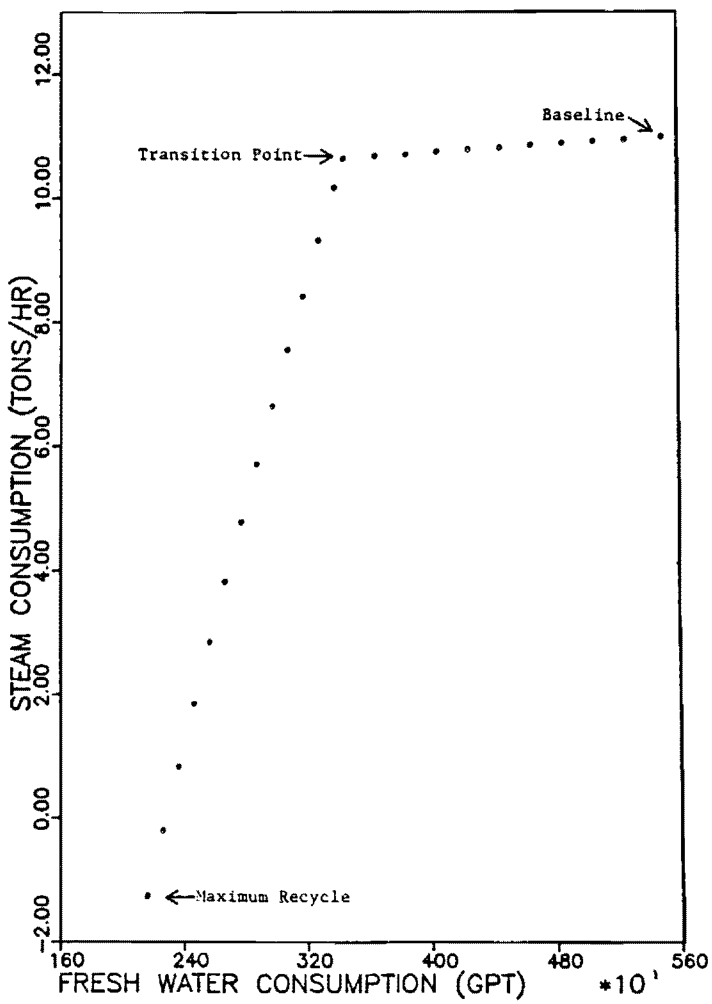


Figure V-17. STEAM CONSUMPTION FOR PROPER WIRE TEMPERATURE, OPTIONS 1 & 2

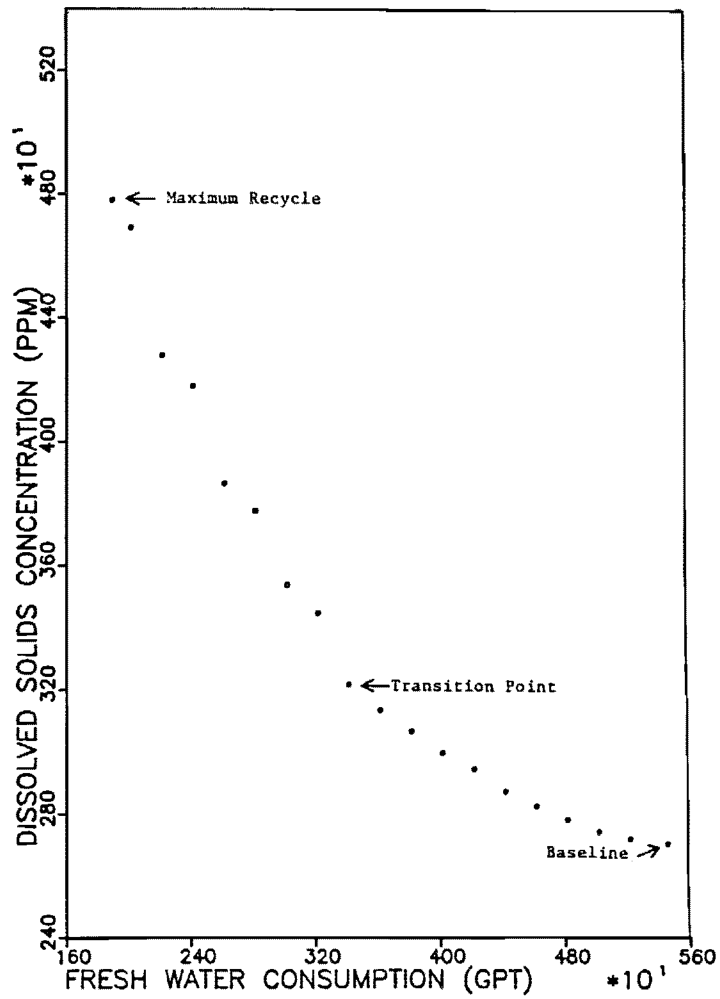


Figure V-18. DISSOLVED SOLIDS BEHAVIOR AT THE HEADBOX, OPTIONS 1 & 3

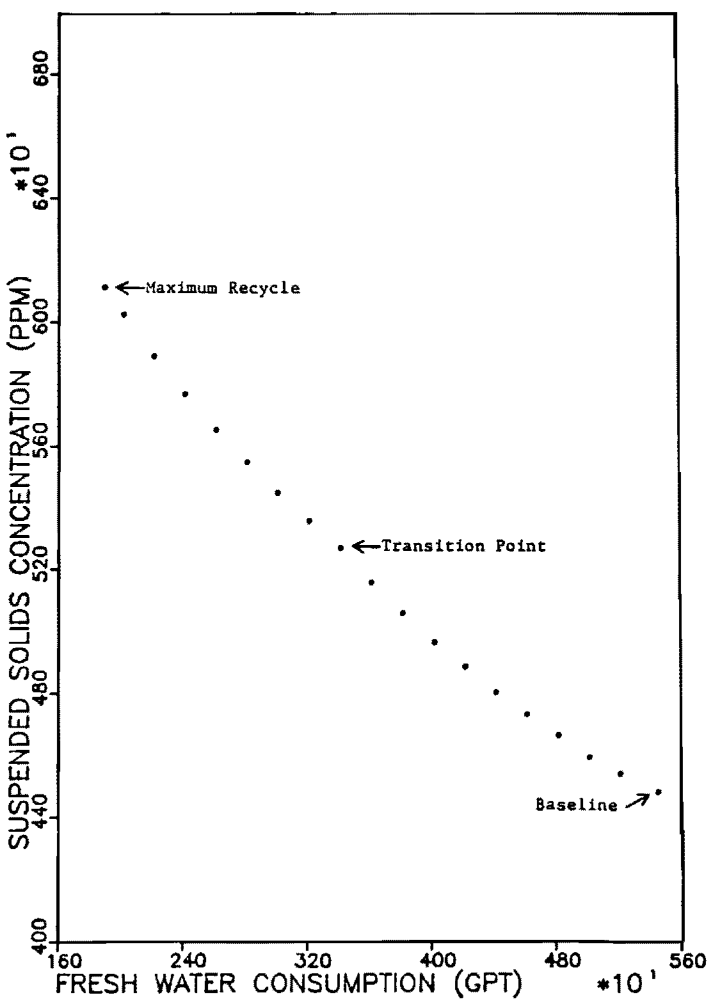


Figure V-19. SUSPENDED SOLIDS BEHAVIOR AT THE HEADBOX, OPTIONS 1 & 3

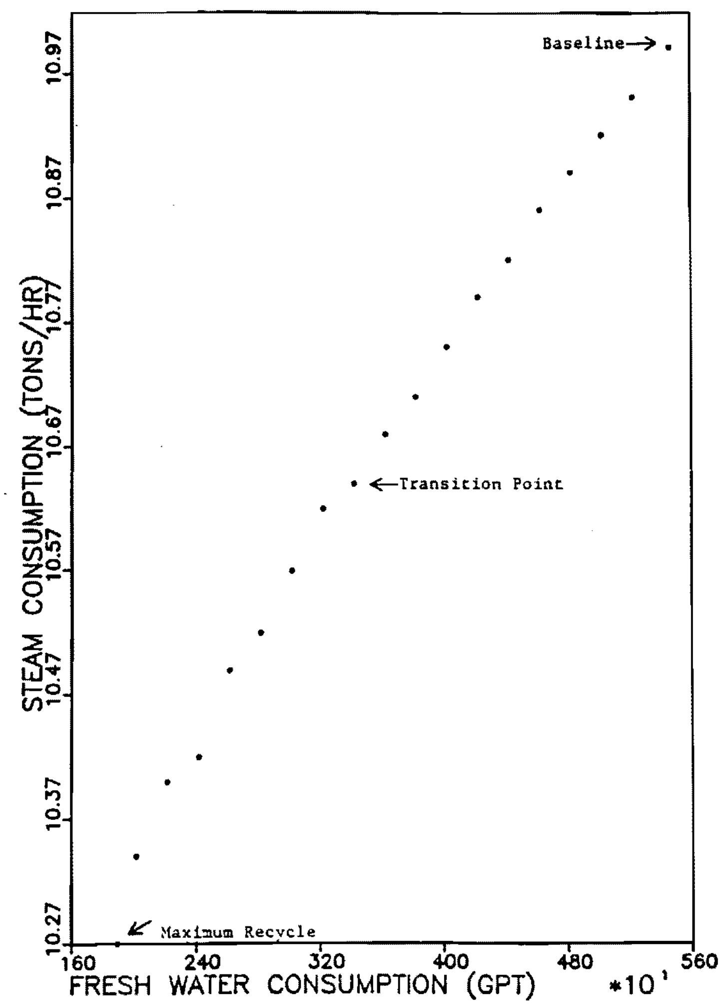


Figure V-20. STEAM CONSUMPTION FOR PROPER WIRE TEMPERATURE, OPTIONS 1 & 3 to the different circuits to which the recycle is added. Option 3 is recycled directly into the headbox water circuit, whereas Options 1, 2, and 4 affect headbox water quality less directly through the white water circuit. As in the previous case, operational constraints were violated, especially for the dissolved solids, as concentrations at total recycle reached 4800 ppm; suspended solids at the same consumption level reached 6100 ppm(Figure V-19). Both values are greater than common mill limits allow.

Case 7

For the case of Options 2 and 3 executed in combination (Figures V-21 through V-23), the dissolved solids again reached a concentration beyond the operational limit, although at the somewhat lower level of 4100 ppm; however, the suspended solids concentration was not so high, reaching only 5000 ppm (1000 ppm below maximum mill levels).

The curves for the combination of Options 2 and 3 almost mirror those of option combination 1 and 3. Indeed, the similarity in behavior between individual Options 1 and 2 has been apparent in every case in which these options have been involved. The method of value reduction (recycle as opposed to direct reduction in the former case) does not influence the relationship between solids buildup and consumption rate. This is a significant point in determining how reduction could be achieved in a typical mill process. It would seem that the choice could be made purely from capital cost considerations rather than differences between the effectiveness of one option over another in preserving proper water quality.

Cases 8, 9, and 10

The last set of cases performed involved the execution of the first three individual options (options 1-3) at 50% recycle into the brown stock screen room and decker (Option 4). The effects these scenarios impose upon headbox water quality are illustrated in Figures V-24 through V-32. It was hoped that these alternatives might give some insight into the effect of upstream recycle upon carryforward, and also give an impression of this effect upon the process with the first three options in operation. As in the previous cases, three plots were generated for each execution, illustrating the relationship between dissolved solids, suspended solids, and steam consumption into the paper mill versus the mill water consumption.

For all three of these last cases, the basepoint moved to 4700 ppm for the suspended solids, 2950 ppm for the dissolved solids, and a steam consumption rate of 13.5 tons per hour. Also, in all three cases, the shape of the curves did not change from the cases of the options run independently. However, the magnitude of the changes for each characteristic was larger, perhaps due to the

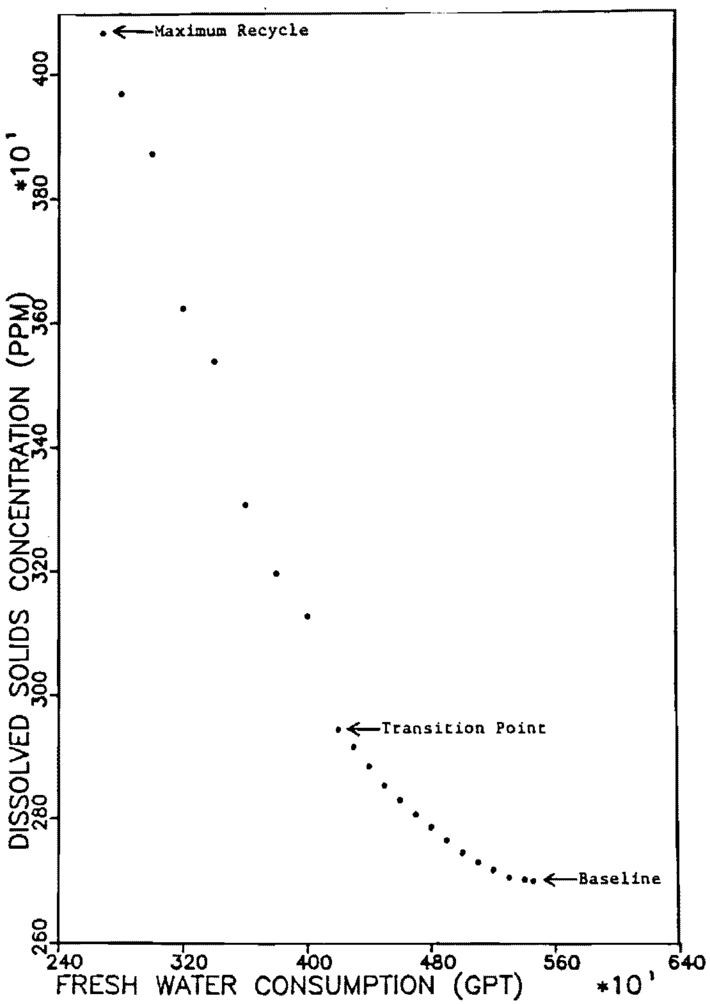


Figure V-21. DISSOLVED SOLIDS BEHAVIOR AT THE HEADBOX, OPTIONS 2 & 3

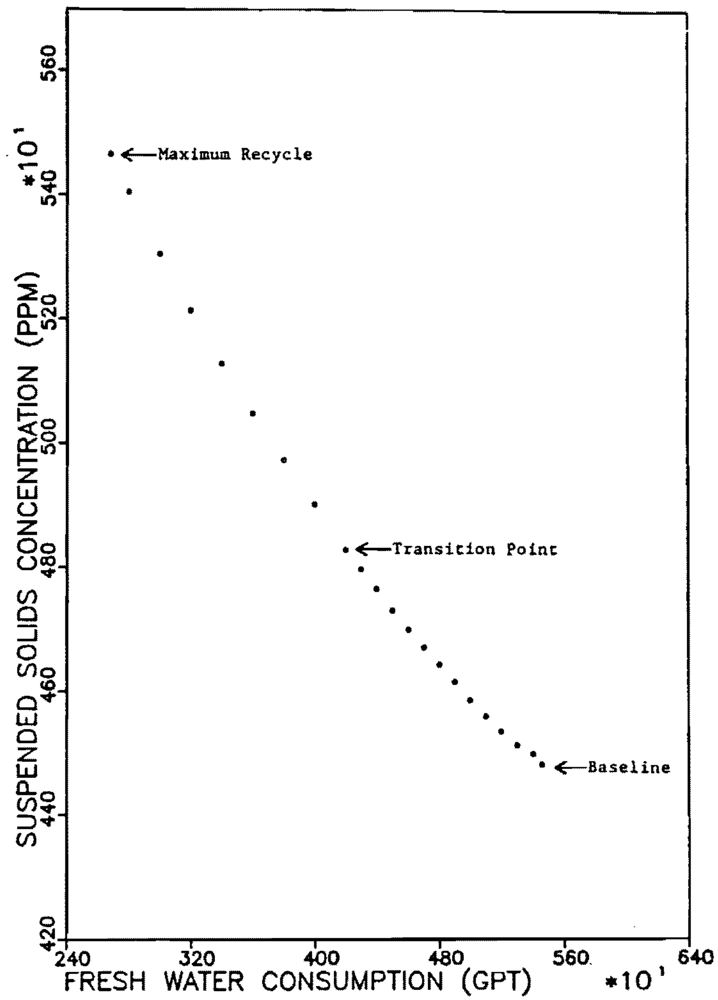


Figure V-22. SUSPENDED SOLIDS BEHAVIOR AT THE HEADBOX, OPTIONS 2 & 3

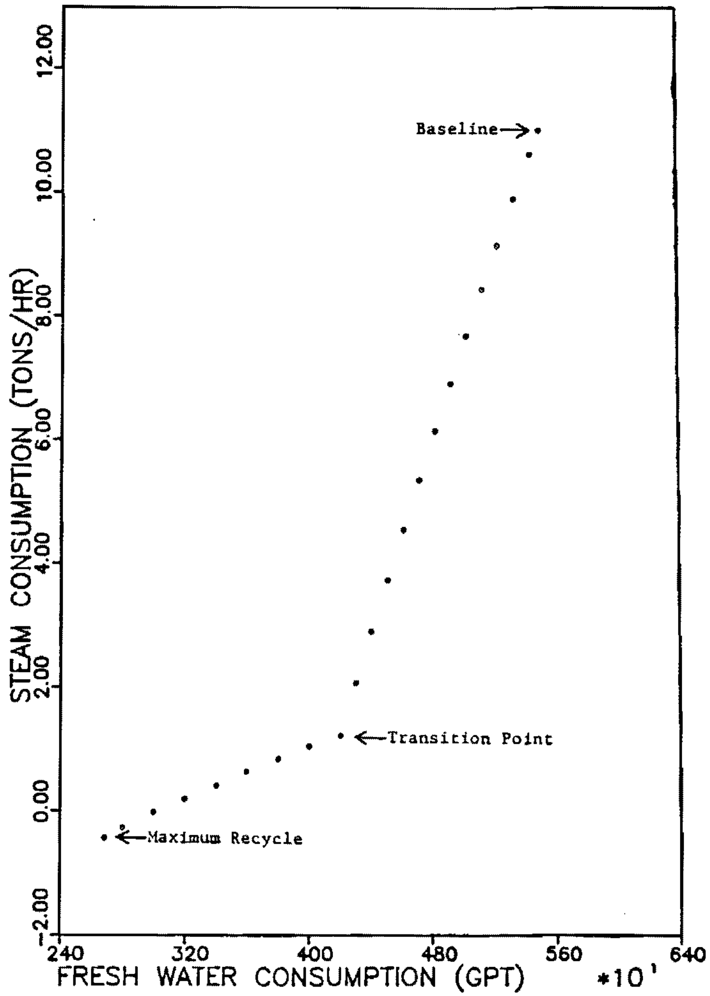


Figure V-23. STEAM CONSUMPTION FOR THE PROPER WIRE TEMPERATURE, OPTIONS 2 & 3

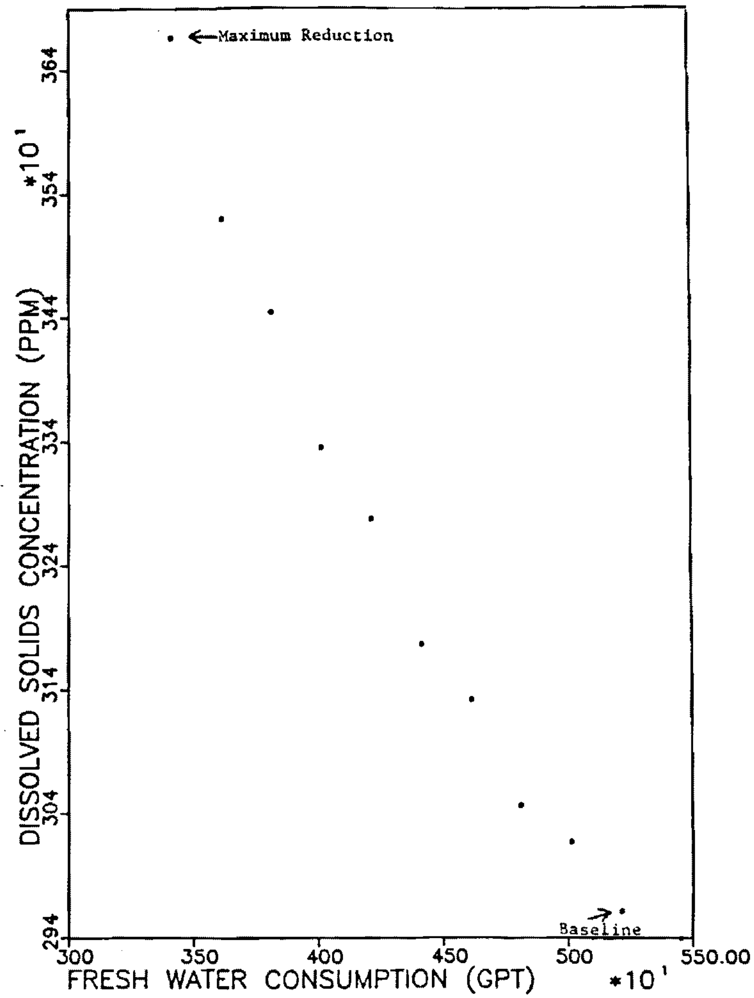


Figure V-24. DISSOLVED SOLIDS BEHAVIOR AT THE HEADBOX, OPTION 1 AT 50% RECYCLE TO WASHERS

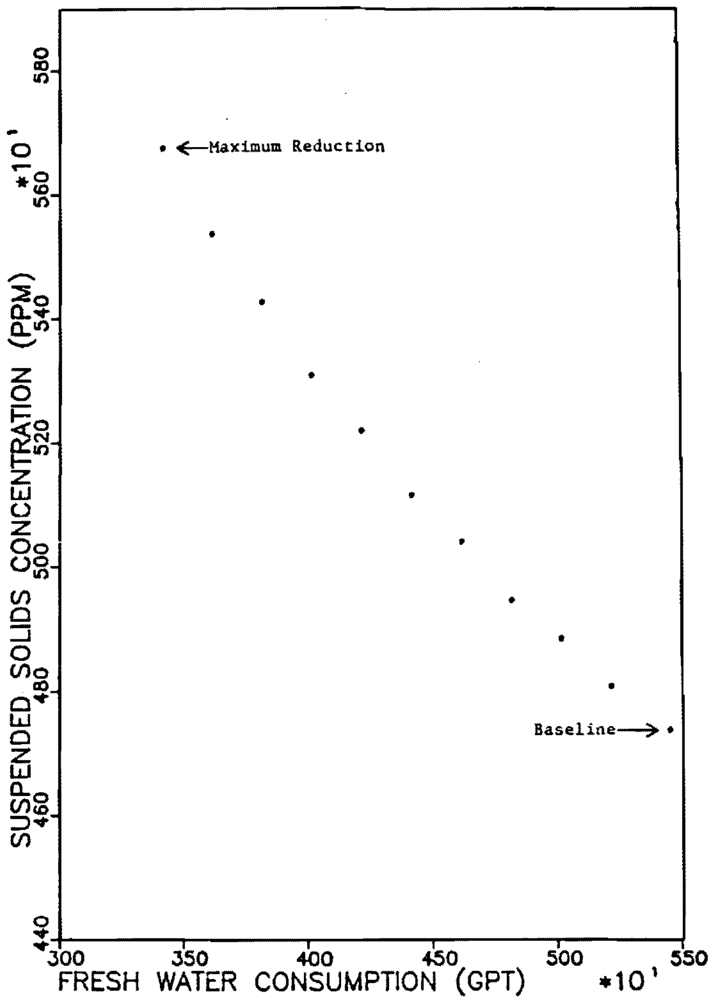


Figure V-25. SUSPENDED SOLIDS BEHAVIOR AT THE HEADBOX, OPTION 1 AT 50% RECYCLE TO WASHERS

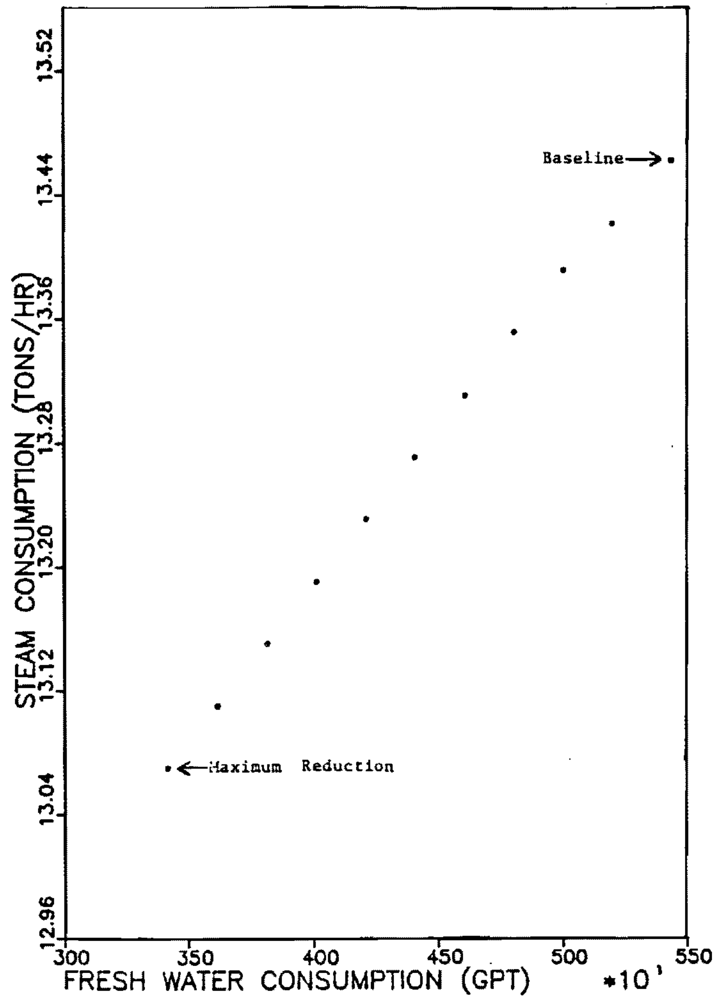


Figure V-26. STEAM CONSUMPTION FOR PROPER WIRE TEMPERATURE, OPTION 1 AT 50% RECYCLE TO WASHERS

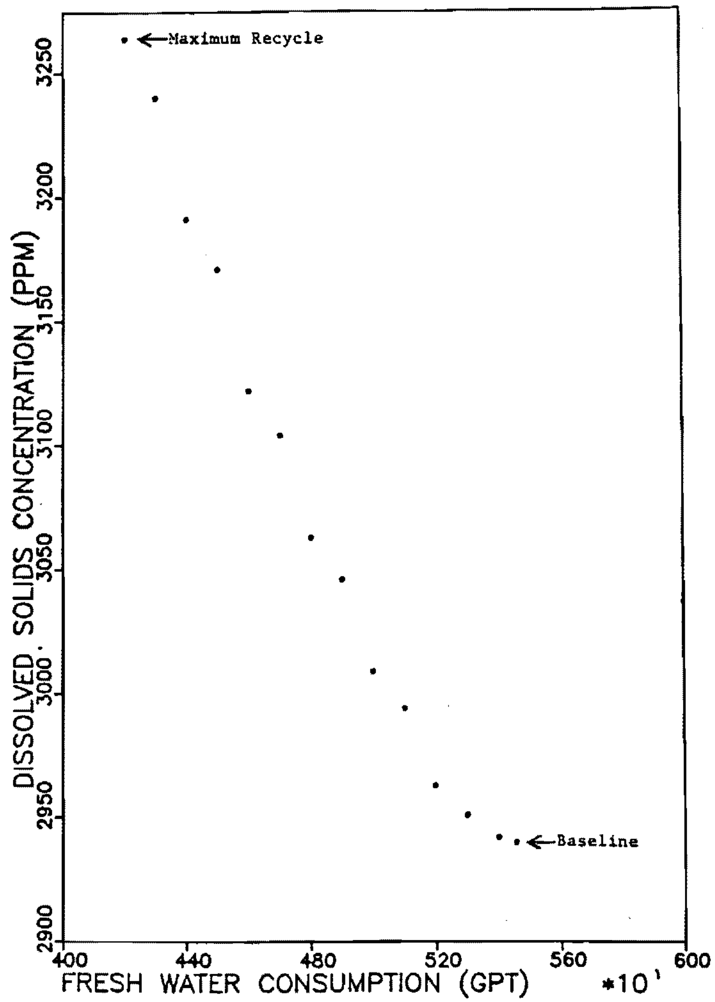


Figure V-27. DISSOLVED SOLIDS BEHAVIOR AT THE HEADBOX, OPTION 2 AT 50% RECYCLE TO WASHERS

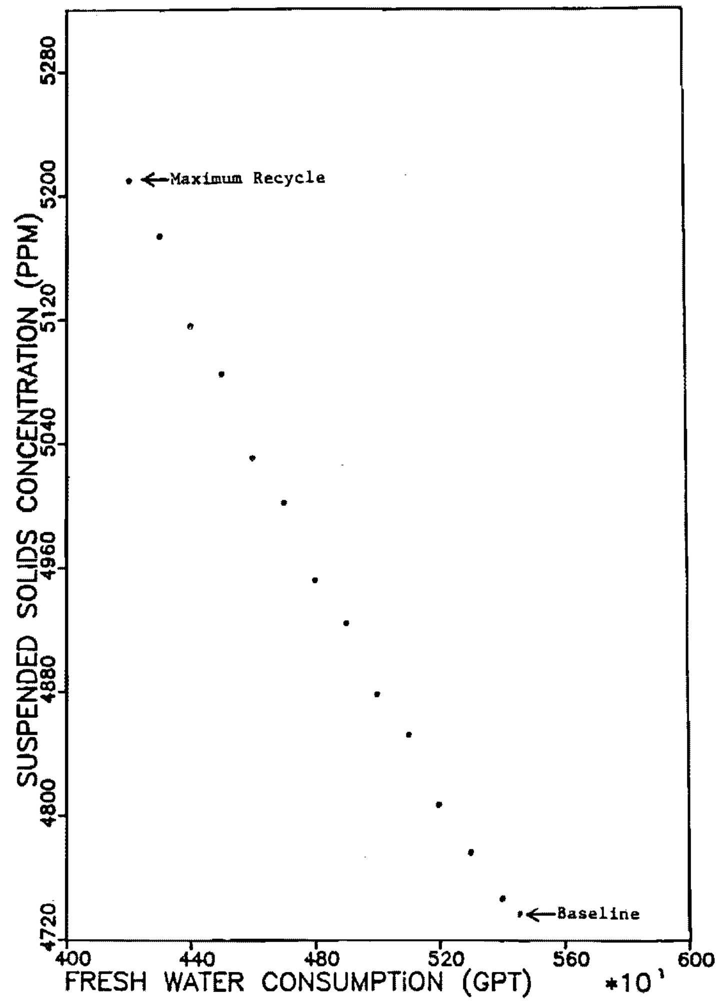


Figure V-28. SUSPENDED SOLIDS BEHAVIOR AT THE HEADBOX, OPTION 2 AT 50% RECYCLE TO WASHERS

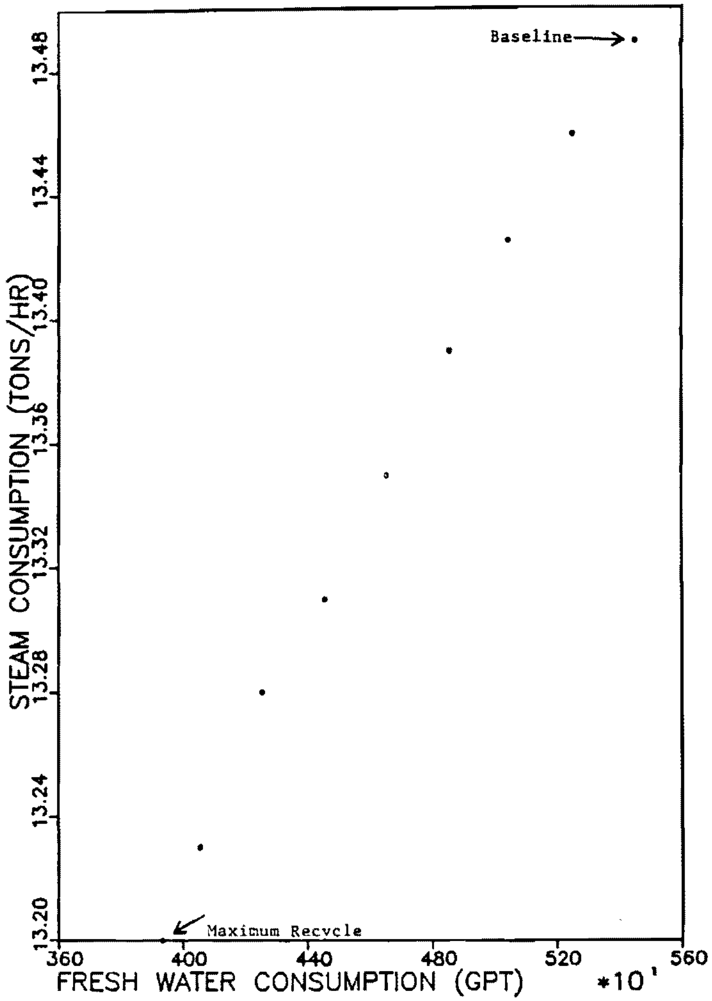


Figure V-29. STEAM CONSUMPTION FOR PROPER WIRE TEMPERATURE, OPTION 2 AT 50% RECYCLE TO WASHERS

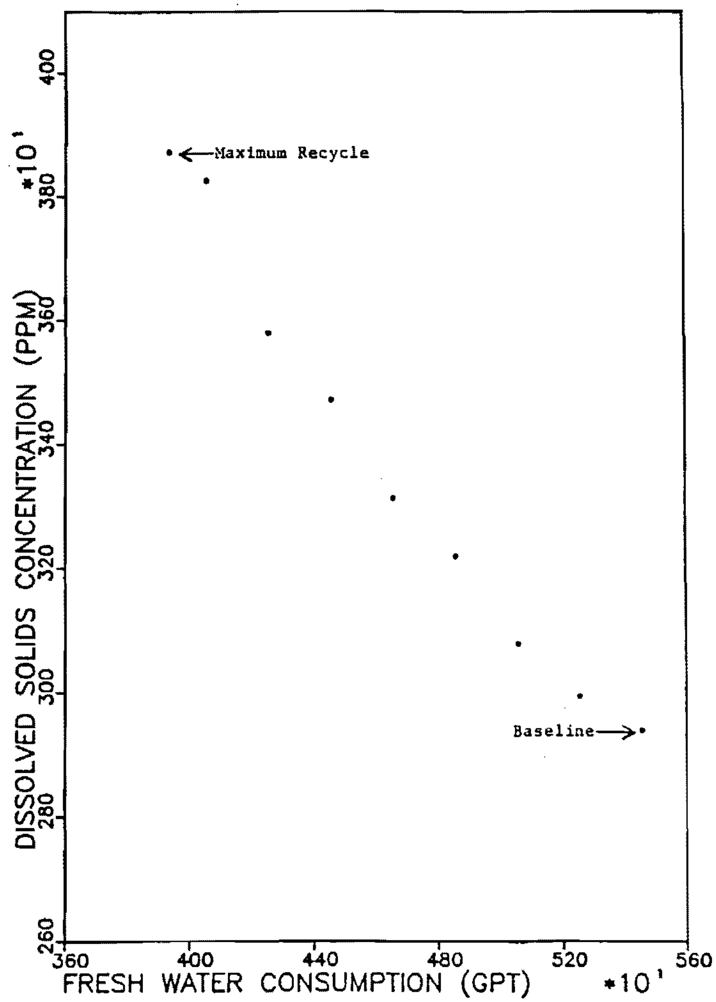


Figure V-30. DISSOLVED SOLIDS BEHAVIOR AT THE HEADBOX, OPTION 3 AT 50% RECYCLE TO WASHERS

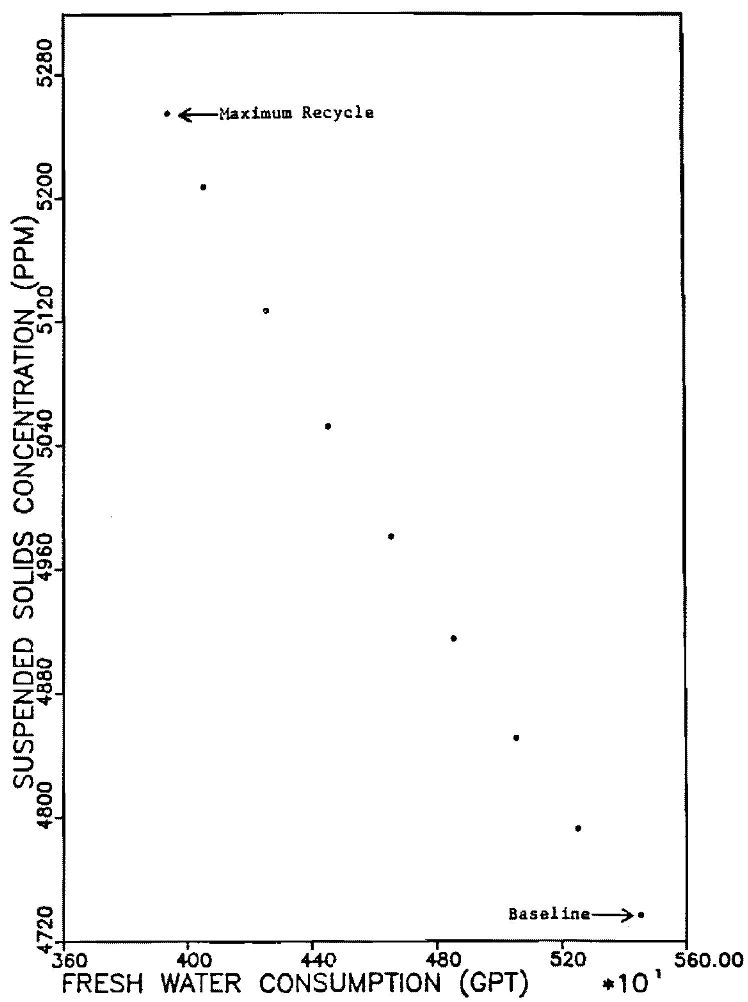


Figure V-31. SUSPENDED SOLIDS BEHAVIOR AT THE HEADBOX, OPTION 3 AT 50% RECYCLE TO WASHERS

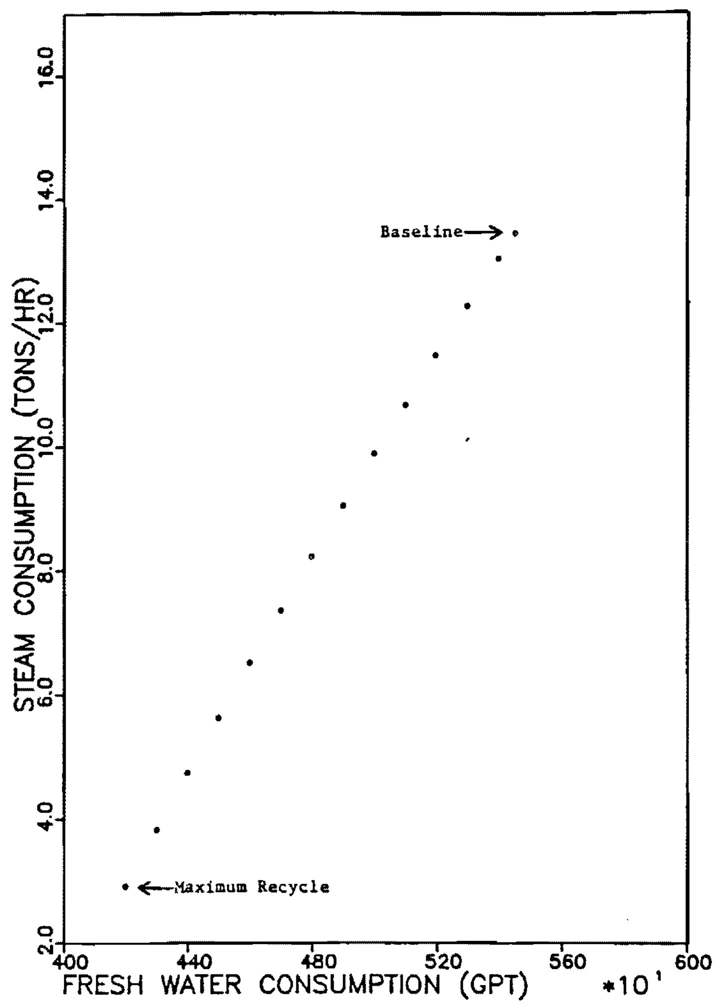


Figure V-32. STEAM CONSUMPTION FOR PROPER WIRE TEMPERATURE, OPTION 3 AT 50% RECYCLE TO WASHERS effect upon the brown stock by the recycled white water. In no case was a constraint violated, with the highest dissolved solids concentration reached for Option 2, a value of 3000 ppm. Based on these results, all three of these alternative process flows are operational.

Those mills that operate machines at ambient temperatures may have a far more significant savings potential at higher levels of white water recycle. Benefits would include a net steam savings in drying, thus yielding greater cost effectiveness. A medium sized linerboard mill instituted a similar program by increasing the stock temperature (to the dryer section) from 120°F to 150°F. This yielded an annual energy savings of almost $600,000 per year.[5]

The employment of greater white water reuse in the future should be justifiable in terms of energy conservation and/or increases in productivity, especially in those mills that operate paper machines at ambient temperatures and that utilize steam to maintain machine temperatures. Even mills that are temperature limited due to sizing requirements could operate machines at as high a temperature as practical. Production costs and energy benefits come from:

- Improved drainage during formation
- Better press section efficiency
- Higher sheet temperature to the dryers resulting in a lower steam demand on the dryers and/or higher overall production
- Lower chemical consumption for white water treatment
- Less fiber loss

Of course documented problems[18] of increased corrosion, biological growth control, and sizing efficiency must be weighed against the potential benefits. It is probable that on the average, greater reuse is possible before these problems outweigh the potential benefits on a typical machine.

References - Section V

1. Wallace, B., "Controlling Moisture on Paper Machines Results in Significant Energy Savings," Paper Trade Journal, November, 1979 (p. 36).

2. Hartley, E., "Energy Savings from High Temperature Stock on the Paper Machine," AIChE, 1980.

3. Aldrich, L., "White Water Reuse on a Fine Paper Machine," TAPPI, Vol. 56 (3), 1973 (p. 92).

4. Smith, C.B., "Reuse of Wastewater," Industrial Process Design for Pollution Control, an AIChE Workshop, American Institute of Chemical Engineers, New York, NY, Vol. 7, 1975 (p. 49).

5. Hodges, C., "Optimum Use of Steam Showers for the Paper Machine," TAPPI, Vol. 60 (7), 1977 (p. 94).

6. Reeve, D., et al., "The Closed-Cycle Bleached Kraft Mill - 1978," TAPPI, Vol. 62 (8), 1979 (p. 51).

7. Nelson, Yankowski, et al., "Water Reuse in Bleaching - Panel Discussion," TAPPI, Vol. 55 (6), 1972 (p. 933).

8. Rapson, W., and Reeve, D., "The Effluent-Free Bleached Kraft Pulp Mill," TAPPI, Vol. 56 (9), 1973 (p. 112).

9. Rickles, R.N. and Balakrishnan, S., "By-Product Recovery and Pollution Control," Water and Wastes Engineering, Vol. 6 (9), 1969 (p. E26).

10. Liebergott, N., et al., "Gas Phase Bleaching of Softwood and Hardwood Kraft and Kraft Oxygen Pulps," 1976 International Pulp Bleaching Conference, Chicago, IL, 1976.

11. Reeve, D., et al., "Effluent-Free Bleached Kraft Mill", 1976 International Pulp Bleaching Conference, Chicago, IL, 1976.

12. Casey, J., Pulp and Paper Chemistry and Chemical Technology, Volume II, 3rd Ed., Wiley - Interscience, New York, NY, 1980.

13. Histed, J., "Water Reuse and Recycle in Kraft Bleacheries," Pulp and Paper Magazine, Canada, Vol. 74 (12), 1973 (p. 80).

14. Kelppe, P., and Rogers, C., "Survey of Water Utilization and Waste Control Practices in the Southern Pulp and Paper Industry," Water Resources Research Institute, U.N.C. Project #A-036-NC, 1970.

15. Carpenter, W., et al., "Characteristics of Effluents from Conventional and Oxygen Bleaching Sequences," TAPPI, Vol. 59 (11), 1976 (p. 81).

16. Rowlandson, G., "Oxygen Pulp Bleaching Cuts Waste Effluents," Chemical Engineering, Vol. 50 (20), 1973 (p. 78).

17. Coats, J.G., Jr., "Water Conservation in the Design of New Paper Machine Installations," TAPPI, Vol. 15 (8), 1968 (p. 95A).

18. Buchman, S.J., "Water Reuse and Deposits Control," Southern Pulp and Paper Magazine, Vol. 36 (4), 1973 (p. 17).

19. Alexander, S. D., and Robbins, R. J., "The Buildup of Dissolved Electrolytes in a Closed Paper Mill," TAPPI, Vol. 60 (12), December 1977 (pp. 117-120).

20. Heller, P., Scott, W. P., and Springer, A. M., "Potential Operating Probems under Conditions of Complete Water Reuse," TAPPI, Vol. 62 (12), December 1979 (pp. 79-84).

21. Martin-Lof, T., Franzen, C., Heinegard, C., and Wahren, D., "Establishment of a Closed System for the Paper-Making Process," TAPPI, Vol. 56 (12), December 1973 (pp. 121-126).

22. Stream Improvement Technical Bulletin No. 287: The Relationship Between Process Water Quality Characteristics and its Reuse Potential in Fine Paper Mills, The National Council of the Pulp and Paper Industry for Air and Stream Improvement, Inc., New York, NY, August 1976.

23. Streebin, Leale, Reid, George, Law, Paul, Hogan, Charles and Ruppersberger, John, "Water Reuse in a Paper Reprocessing Plant," TAPPI, Vol. 59 (5), May 1976 (pp. 105-108).

24. Stream Improvement Technical Bulletin No. 339: The Relationship Between Process Water Quality and Its Reuse Potential in Unbleached Kraft Mill Paper and Board Machine Systems. The National Council of the Pulp and Paper Industry for Air and Stream Improvement, Inc., New York, NY, November 1980.

25. Shema, B. F., "Some Problems Associated with Water Reuse," American Paper Industry, Vol. 55 (9), September 1973 (pp. 31-33).

26. Wilkinson, J. J., "A Practical Approach to Water Conservation in a Paper Mill," Pulp and Paper International, Vol. 15 (5), May 1973, (p. 59).

27. Bush, W., "The Closed Mill Concept," TAPPI, Vol. 61 (10), 1978, (p. 54).

28. Czappa, D. J., "In-Mill Close-Up: Components of a Successful Program," TAPPI, Vol. 61 (11), 1978 (p. 97).

29. Courtney, S. M., "Water System Closure," TAPPI, Vol. 62 (10), October 1979 (p. 47).

30. Emmerman, L. J., "Saving Energy Through Recycling Paper Mill Process Water," American Paper Industry, Vol. 56 (4), April 1974, p. 20).

31. Morrisey, D., American Paper Institute, Vol. 54, 1972 (p. 15).

32. Sommerfield, J. T., and Hartley, E. M., "Energy Management and Computers in the Pulp and Paper Industry," Proceedings of the 1981 Industrial Energy Conservation Technology Conference, Houston, TX, April 1981 (p. 231).

33. Springer, A. M., and Ortega Garcia, R., "Vacuum Pump Seal Water: Strategies for Management in Pulp, Paper Mills," Pulp and Paper, Vol. 53 (8), July 1979 (p. 74-77).

34. Hartley, E. M., Battaglia, G. M., Himes, W. B., Valentine, Greer E., and Wyvill, J. Craig, An Evaluation of the Potential for Water Conservation in the Georgia Pulp and Paper Industry, Georgia Institute of Technology, Engineering Experiment Station, Atlanta, GA, June 1981.

Section VI

PROJECTED WATER DEMANDS IN THE PULP AND PAPER INDUSTRY

Data obtained from several sources shows that the production of pulp and paper for 1981 amounted to approximately 330,000 tpd.[1,2] It is estimated that production will increase to approximately 561,000 tpd by the year 2000.[3] This equates to an average annual growth rate of 2.8%. Table VI-1 shows the current and projected production for the ten study subcategories. The projections were made by assuming a uniform growth rate for all sectors during this period.

To estimate future water usage for the industry, factors such as historical trends, available and anticipated recycle/reuse, technology energy supplies, environmental regulations, water availability, the quality of receiver streams, and conversations with knowledgeable personnel within the industry were analyzed. Table VI-2 shows the current and projected water usage rates for the ten production subcategories studied. For the year 2000, two sets of projections are given. The "Expected Averages" values listed in Table VI-2 were developed using the water demands associated with the best in-place recycle/reuse technologies found today. This selection reflects an expectation that continued pressures on mills in each production subcategory to reduce energy, fiber, chemical, and waste treatment costs will ultimately result in widespread adaption of these proven technologies by the year 2000. New technologies developed in the years to come, as has occured in the past, will not likely experience widespread adaption by the year 2000 unless unusual changes take place. No such changes are anticipated at this time.

The "Estimated Best Achievable" values on the other hand, were obtained by reviewing both existing and potential recycle/reuse technologies. Here, the findings discussed in Section V were applied as feasible to each production subcategory to arrive at the best likely recycle/reuse scheme for each, together with its resultant new level of freshwater demand. It is expected that few mills will indeed undertake these measures for achieving and possibly even exceeding the levels projected here. It is also anticipated that few mills in the industry will correspondingly reach such values. This is because of the degree of risk and costs associated with these new concepts. For mills to seriously consider these concepts, they will likely face unusual pressures to either reduce freshwater intake or lower operating costs. Such unusual pressures are typically needed to justify undertaking such experimental endeavors.

Current and projected total water demands for the ten subcategories are shown in Table VI-3. These values are the products generated by multiplying production (tpd) times the corresponding water usage rate (gallons per ton) for each category. The values in the column "Most Probable-2000" are the products of the projected production times the "Expected Averages-2000" water usage rates. "Best Achieveable" was obtained by multiplying the projected production times the "Estimated Best Achieveable" values. The values in the column "Status Quo" were

Table VI-1. GROWTH OF INDUSTRY (PRODUCTION)

Subcategory	1981 (tpd)	2000 Production (tpd)
Dissolving Kraft	3,350	5,862
Market Bleached Kraft	5,195	9,091
BCT Bleached Kraft	9,190	16,082
Alkaline Fine Paper	13,100	22,925
Unbleached Kraft	30,492	53,361
Unbleached Kraft & S.C.	13,504	23,632
Dissolving Sulfite	1,550	2,713
Papergrade Sulfite	4,309	7,540
Miscellaneous Integrated	61,090	106,908
Non-integrated Fine Paper	7,478	13,087

Table VI-2. PRODUCT WATER DEMAND

Subcatagory	Current Averages 1981 (gal/ton)	Expected Averages 2000 (gal/ton)	Estimated Best Achievable 2000 (gal/ton)
Dissolving Kraft	44,200	32,000	29,000
Market Bleached Kraft	35,000	21,000	16,000
BCT Bleached Kraft	37,600	23,000	17,000
Alkaline Fine Paper	44,900	25,000	18,000
Unbleached Kraft	15,800	8,000	4,000
Unbleached Kraft & S.C.	11,400	8,000	4,000
Dissolving Sulfite	70,600	60,000	50,000
Papergrade Sulfite	51,400	25,000	17,000
Miscellaneous Integrated	27,500	13,000	10,000
Non-integrated Fine Paper	18,400	9,000	3,000

Table VI-3. TOTAL WATER USAGE

SUBCATEGORY	1981 (MGD)	MOST PROBABLE 2000 (MGD)	BEST ACHIEVABLE 2000 (MGD)	STATUS QUO 2000 (MGD)
Dissolving Kraft	148	188	170	259
Market Bleach Kraft	161	191	145	318
BCT Bleached Kraft	329	370	273	605
Alkaline Fine	588	573	413	1029
Unbleached Kraft	480	427	213	843
Unbleached Kraft & S.C.	154	189	95	269
Dissolving Sulfite	110	162	136	191
Papergrade Sulfite	221	188	128	387
Integrated Miscellaneous	1631	1389	1069	2940
Non-Integrated	141	117	39	241
TOTAL	3963	3794	2681	8082

obtained by multiplying the projected production for the year 2000 times the water usage rates of 1981.

From Tables VI-1, VI-2 and VI-3 it can be seen that while production is expected to increase 70% by the year 2000, the total volume of water used by the industry is expected to actually decrease relative to 1981 total water usage. This is because projected reductions in water usage through recycle/reuse are expected to actually exceed the forecasted 70% production growth rate. If no change in the current water usage rate were to occur, anticipated production increases would result in much higher water usage values in the year 2000. As shown in the totals of Table VI-3 the "Status Quo" value would be 53% (4288 MGD) more than the projected "Most Probable" while the "Status Quo" would be 67% (5401 MGD) more than the "Estimated Best Achievable".

References - Section VI

1. Post's Pulp and Paper Directory, Miller Freeman Publications, San Francisco, CA, 1981.

2. Lockwood's Directory of the Paper and Allied Trades, Lockwood Publishing Co., Inc., New York, NY, 1981.

3. Predicasts Forecasts, No. 81, Predicasts Inc., Cleveland, OH, 1981.

Section VII

CONCLUSIONS AND RECOMMENDATIONS

In Section VI, projections were presented reflecting the future of water demand in major water consuming sectors of the pulp and paper industry. These projections were based on assumptions related to current and anticipated conditions within the industry.

The projections show that there is a strong potential for the pulp and paper industry to reduce future freshwater consumption by over 4.2 billion gallons/day in the year 2000 and that further this can be accomplished through the application of recycle technology that is currently in place today in some mills. If further consideration is given to recycle and reuse technology under development, this potential for freshwater consumption reduction could increase to a level of over 5.4 billion gallons/day by the year 2000.

The primary motivation for undertaking recycle/reuse measures is the economic attractiveness of their application. It is here that actual cost savings figures are difficult to generate, yet indications abound that energy, chemical, and fiber savings alone may justify the costs involved. Mills today that are applying such technology have been quick to point out that they initially were unable to quantify the full cost savings potential of their programs. Yet when the programs were finally implemented, the total chemical, energy, and fiber cost savings recognized often exceeded the original estimates. Furthermore, some have commented that these savings alone justified the expenditures made. Unfortunately, this message is not being conveyed to the majority of mills throughout the country who continue to show a reluctance to make such investments.

It is here that a second, and somewhat more subtle incentive may force many mills to look more closely at recycle/reuse. That incentive is the anticipated enactment of environmental legislation in the not too distant future. While this legislation has recently been in a state of delay, final enactment is imminent; and indications show that these regulations will likely require utilization of the best current treatment technology in achieving their discharge standards. Such technology is expected to force mills, that are either out of compliance or anticipating increased production beyond the capability of their current treatment facilities, to look at water recycle/reuse as a cost effective means of achieving compliance.

Perhaps the most uncertain variable which could increase efforts in recycling/reusing water is the threat of water shortages. Projections[1] have shown that ground and surface water overdraft is expected to create problems primarily in the southwest and lower

Mississippi Valley portions of the country where water demand by pulp and paper producers is not significant. Even so, it is possible that serious local water shortages might still impact selected mills around the country. Should such local shortages prove significant, there is every probability that mills in affected localities will consider both recycle and the reuse of reliable supplies of locally available wastewater as a hedge against unscheduled shutdowns. Obviously the extent to which mills resort to such measures will be directly related to the perceived risk of shutdown. Based on existing shortage projections, however, the extent of such activity in the pulp and paper industry is expected to be very limited.

A number of areas for further research have been identified as a result of this study. Perhaps the most significant is the need to continue the development of computer models capable of accurately depicting technical and economic impacts related to recycle and reuse options. The existing models reviewed during this study commonly lacked iterative capabilities to rapidly select an optimum point or the ability to simultaneously track the savings versus cost of various options. Ironically, new software packages are emerging today which hold considerable promise toward meeting these objections. The brunt of the development work needed is in the area of adapting these new programs to the unique intricacies of the various pulp and paper production cycles.

Another area for further research is in the development of better screening techniques for solid/liquid separation in pulp and paper mills. Current screening technologies are nothing more than gross separators frequently limiting a mill's ability to achieve a higher degree of recycle. Research in the area of micro-screening is needed. The employment of micro-screening technology holds a potential key to more successfully recycling water, and promises to allow better chemical and fiber collection as well.

The area of waste stream segregation is one which has been given some attention today yet which still falls short of its potential. Many mills employ sewer systems which mix, dilute, and concentrate waste streams prior to treatment. Such actions can result in higher than necessary volumes going through the entire waste treatment facility. Research in the area of staged treatment and further segregation of waste streams may open new horizons for achieving legislative compliance and increasing the potential for water reuse.

One final area in which further research is needed is in developing better corrosion technology to deal with increased water recycle/reuse. The current approach of resorting to chemical additives and/or the use of stainless and other exotic metal technology is costly. A number of new composite materials are coming on the market today which may hold promise for bringing about the prevention of corrosion at potentially lower costs. Such composites might possibly be used either as liners or molded to replace steel components currently in use. The future of recycle and reuse may hinge on the availability of low cost, corrosion inhibiting technology.

The policy implications for achieving more efficient recycling and reuse of water clearly indicate a need for comprehensive coordinated programs which take into account the full range of national and regional water needs. Unified planning efforts spearheaded by members of local industry, government, and the community at large are needed to insure that regional water-related problems are minimized. Continued federal involvement is needed to assure that inter-regional issues are addressed and general research efforts are coordinated. Such local, regional, and federal involvement should assure that proper direction is given to the management and use of the nation's water resources.

References - Section VII

1. United States Water Resources Council, "The Nation's Water Resources 1975-2000, Volume 1: Summary" U.S. Government Printing Office, Washington, D.C. 1979.

Appendix A

GLOSSARY

Activated Sludge Process - A high rate biological oxidation process. The significant feature of the process is the recycle of a biologically-active sludge formed by settling the microorganism population from the aeration process in a clarifier. Waste is treated in a matter of hours rather than days.

Aeration - The process of being supplied or impregnated with air. Aeration is used in biological treatment to dissolve oxygen in the wastewater. This dissolved oxygen is required by microorganisms as they feed on organic matter in the wastewater.

Air Dry Ton (ADT) - Measurement of production including a moisture content of 10% by weight.

Bale - A standard bale of wastepaper is 72" long, 32" wide, and 28" deep, with a content of about 37 cubic feet and weighing 900 to 1,000 lbs. The size and weight may vary with the grade of paper. A bale of pulp varies in weight from 400 to 500 lbs and is approximately 30"x30"x72" in size. A bale of rags varies in weight from 700 to 1,300 lbs and will vary in dimensions according to the press used. Typical dimensions are 26"x30"x72", 26"x42"x72", or 26"x52"x64". A bale of rags weighs 61 to 62 lbs.

Barker - A piece of equipment designed to remove the bark from a log.

Barking - The operation of removing bark from pulpwood prior to processing. This is carried out by means of a knife, drum, mechanical abrasion, hydraulic barker, or by chemical means.

Beater - A machine consisting of a tank or "tub," usually with a partition or "midfeather," and containing a heavy roll revolving against a bedplate. Both roll and bedplate may contain horizontal metal bars set on edge. Pulp or wastepapers are put into the tub of the beater, and water is added so that the mass may circulate and pass between the roll and the bedplate. This action separates the material and frees the fibers preparatory to further processing. Fillers, dyestuffs, and sizing materials may be added to the beater and thus incorporated with the paper stock. Many modifications in design have been developed without changing the basic principles. (See also Refiner.)

Biological Oxidation - The process by which bacterial and other microorganisms oxidize organic materials to simpler compounds and use these for growth and energy. Self-purification of waterways and biological waste treatment systems such as activated sludge, trickling filter, and aerated stabilization depend on this principle.

Black Liquor - The used cooking liquor recovered from the digester. It may also be referred to as spent cooking liquor. Strong black liquor refers to the liquor after it has been concentrated by an evaporator to a level suitable for combustion. Prior to evaporation, it is referred to as weak black liquor.

Bleaching - The brightening and delignification of pulp by the addition of oxidizing chemicals such as chlorine or reducing chemicals such as sodium hypochlorite.

Blow - Ejection of the chips from a digester, or waste solids from a boiler.

Blowdown - The liquid and solid waste materials ejected from a pressure vessel such as a boiler.

Blow Pit - A large tank under a digester which receives the discharged chips and liquor from the digester. A constructed stainless steel plate within the blow pit acts to break up the chip structure into individual fibers of pulp upon impact.

Biochemical Oxygen Demand (BOD_5) - Quantity of dissolved oxygen utilized in the biochemical oxidation of organic matter in a specified time (5 days) and at a specified temperature. It is not related to the oxygen requirements in chemical combustion, being determined entirely by the biodegradability of the material and by the amount of oxygen utilized by the microorganixms during oxidation.

Brightness - As commonly used in the paper industry, the reflectivity of a sheet of pulp, paper, or paperboard for specified light measured under standardized conditions.

Brightness Unit - An increment of measurement to assess the brightness of paper.

Broke - Partly or completely manufactured paper that does not leave the machine room as salable paper or paperboard; also paper damaged in finishing operations such as rewinding rolls, cutting, and trimming.

Brown Stock - Pulp, usually Kraft or groundwood, not yet bleached or treated other than in the pulping process.

Capacity - Production unit, usually in tons per day.

Causticizing - Process of making white liquor from green liquor by addition of slaked lime. Most Na_2CO_3 is thereby converted to NaOH.

Cellulose - The major polysaccharide component of the cell walls of all woods, straws, fibers, and seed hairs. It is the main solid constituent of wood plants and is the principal raw material of pulp, paper, and paperboard.

Chemical Oxygen Demand (COD) - A measure of the oxygen-consuming capacity of organic and inorganic matter present in water or wastewater. It is expressed as the amount of oxygen consumed from a chemical oxidant in a specific test.

Chemical Wood Pulp - Pulp obtained by digestion of wood with solutions of various chemicals. The principal chemical processes are the sulfite, sulfate (Kraft), and soda processes.

Chest (or Stock Chest) - A tank used for storage of wet fiber or furnish.

Chipper - A machine consisting essentially of a revolving disk equipped with heavy radially-arranged knives, which cuts pulpwood and sawmill waste into slices or chips, diagonal to the grain.

Chips - Small pieces of wood used to make pulp.

Chlorine Dioxide (ClO_2) - A chemical used in pulp bleaching as a water solution, usually in one or more of the latter stages of a multistage equence. It is prepared by a variety of processes at the plant site usually from sodium chlorate, acid, and a reducing agent.

Clarifier - In wastewater treatment, a settling tank which removes solids from wastewater through gravitational settling. The settled material, called sludge, is removed from the tank bottom by a rake arm.

Clay - In general, a natural, earthy, fine-grained material which develops plasticity when wetted, but is hard when baked or fired. Used as filler and for coating paper sheets.

Cleaner - A device which creates a cyclone effect to remove dirt and other rejects from pulp using the differences in density to aid in separation.

Coarse Papers - Paper used for grocery and shopping bags, sacks, and special industrial papers.

Coated - A term applied to paper and paperboard, whose surface has been treated with clay or some other pigment and adhesive mixture or other suitable material, to improve the finish with respect to printing quality, color, smoothness, opacity, or other surface properties. The term is also applied to lacquered and varnished papers.

Color - Refers to standard American Public Health Assn. Platinum Cobalt Test, using standards for color intensity of water samples. Commonly, standards are prepared at various concentrations which later may be referenced as units of color, derived from flow and concentration standards.

Color Plant - The portion of a fine papermill where pulp is dyed or colored prior to being made into paper.

Color Unit - A measure of color concentration in water using NCASI methods.

Composite Sample - A mixture of grab samples collected at the same sampling point at different times.

Consistency - The percentage, by weight, of air dry (or oven dry) fibrous material in a stock or stock suspension. It is also called density or concentration.

Converting - Any operation in which paper is made into a product, not necessarily the final product to be made.

Cooking - Heating of wood, water, and chemicals in a closed vessel under pressure to a temperature sufficient to separate the fibrous portion of wood by dissolving lignin and other nonfibrous constituents.

Cooking Liquor - The mixture of chemicals and water used to dissolve lignin in wood chips.

Couch Pit - A pit or catch basin located under the couch roll on a fourdrinier machine to receive water removed at the couch or wet broke in case of a wet end break.

Couch Roll - A roll primarily involved in dewatering and picking off, or couching, of the newly formed paper web from the wire on which it was formed and partially dewatered. The couch roll is involved in the transfer of the web to the wet press felt for further dewatering.

Countercurrent Washing - A method of washing used on the bleach plant or brown stock washers where fresh water is applied on the last stage showers, and the effluent from each stage is used on the washer showers of the preceding stage.

Cylinder Machine - One of the principal types of paper making machines, characterized by the use of wire-covered cylinders or molds on which a web is formed.

Debarking - See Barking.

Deflaker - A high-speed mixing and agitating machine through which a fibrous stock suspension in water is pumped to obtain complete separation and dispersion of each individual fiber, and break up of any fiber lumps, knots, or bits of undefibered paper.

Density - Weight per unit volume.

Diffusion Washing - Washing pulps with an open-ended vessel by diffusing or passing the wash media through the pulp mass.

Digester - The vessel used to treat pulpwood, straw, rags, or other such cellulosic materials with chemicals to produce pulp.

Disk Refiner - A motor-driven refiner whose working elements consist of one or more matched pairs of disks having a pattern of ribs machined into their faces and arranged so that one disk or the pair is rotated. The other disk is usually stationary, but may be driven in the opposite direction of rotation.

Dissolved Oxygen - Amount of oxygen, expressed in milligrams per liter, dissolved in water.

Dissolved Solids - The total amount of dissolved material, organic and inorganic, contained in water or wastes.

Dregs - The inert rejects from the green liquor clarifier of a pulp mill.

Dregs Washer - A piece of equipment used to wash the green liquor (Na_2CO_3) off the dregs prior to their disposal.

Evaporators - Process equipment used to concentrate spent pulping liquors prior to burning.

Extended Aeration - A modification of the activated sludge process that employs aeration periods of 18 hours or more.

Extraction Water - Water removed during a pulp manufacturing process.

Felt - The endless belt of wood or plastic used to convey and dewater the sheet during the papermaking process.

Fiber - The cellulosic portion of the tree used to make pulp, paper, and paperboard.

Filler - A material, generally nonfibrous, added to the fiber furnish of paper. In paperboard manufacturing, the inner ply or plies of a multiple layer product.

Fine Papers - Papers for printing, reproduction and writing.

Fines - Very short pulp fibers or fiber fragments and ray cells. They are sometimes referred to as flour or wood flour.

Finishing - The various operations in the manufacture and packaging of paper performed after it leaves the paper machine. Finishing operations include supercalendering, plating, slitting, rewinding, sheeting, trimming, sorting, counting, and packaging. Ruling, punching, pasting, folding, and embossing are also sometimes considered as finishing operations.

Flume - A sloped trough with flowing water used to transfer pulpwood from one point to another.

Fourdrinier Machine - A papermaking machine employed in the manufacture of all grades of paper and paperboard. It may be divided into four sections: the wet end, the press section, the drier section, and the calender section.

Freeness - A measure of the rate with which water drains from a stock suspension through a wire mesh screen or a perforated plate. It is also known as slowness or wetness.

Furnish - The mixture of fibers and chemicals used to manufacture paper.

Gland - A device utilizing a soft wear-resistant material used to minimize leakage between a rotating shaft and the stationary portion of a vessel such as a pump.

Gland Water - Water used to lubricate a gland. Sometimes called "packing water".

Glassine Paper - Paper used as protective wrapping of foodstuffs and products including tobacco products, chemicals, and metal parts as well as for purposes where its transparent features are useful (i.e., window envelopes). This paper is grease resistant and has high resistance to the passage of air and many essential oil vapors.

Gloss - The property of a surface which causes it to reflect light that is responsible for its shiny or mirror-like appearance.

Grade - The type of pulp or paper product manufactured.

Greaseproof Paper - Paper used when resistance to oil and grease penetration is necessary.

Green Liquor - Liquor made by dissolving the smelt from the Kraft process water and weak liquor preparatory to causticizing.

Green Liquor Clarifier - A piece of equipment used to separate the dregs from the green liquor, allowing recovery of the green liquor for processing into white "cooking" liquor.

Grinder - A machine for producing mechanical wood pulp or groundwood. It is essentially a rotating pulpstone against which logs are pressed and reduced to pulp.

Grindstone - A natural or artifical stone which is channeled or grooved and used for the manufacture of mechanical, chemi-mechanical, and groundwood pulp.

Groundwood Papers - A general term applied to a variety of papers, other than standard newsprint, made with substantial proportions of mechanical wood pulp together with chemical wood pulps, and used mainly for printing and converting purposes.

Hardwood - A term applied to wood obtained from trees of the angio-sperm class, such as birch, gum, maple, oak, and poplar. Hardwoods are also known as porous woods.

Headbox - The area of the paper machine that uniformly spreads and distributes the dilute stock suspension and from which the stock flows through a slice onto the wire.

Hemicellulose - The secondary component of cell walls of wood consisting primarily of short-chained (low molecular weight) polysaccharides.

Hemp - A tall plant native to Asia having stems that yield a coarse fiber used in the cordate and textile industry. Enters the paper industry as old cordate or rough textile waste.

Hot Ponds - Heated ponds of water used to thaw frozen logs.

Impregnation - The process of treating a sheet or web of paper or paperboard with a liquid such as hot asphalt or wax, a solution of some material in a volatile solvent, or a liquid such as an oil. It is also used as a term to describe a treatment in which fibrous raw materials are infused with a chemical solution prior to a digesting or fiberizing process. Sometimes called pre-impregnation.

Integrated - A term used to describe a pulp and paper mill operation in which all or some of the pulp is processed into paper at the mill.

Jumpstage Countercurrent Washing - Another type of countercurrent washing in which freshwater is used on the last two stages and filtrates from the acid stages are used on the preceding acid stage with the filtrate from the final alkaline stage being used on the preceding alkaline stage.

Jute - The glossy fiber of either of two East Indian plants of the linden family used chiefly for sacking burlap and twine. In paper-making, cuttings from burlap manufacture, washed sugarbagging and wool tares used in wrapping cotton bales are used as raw material sources.

Kiln - A furnace or oven used in the pulp and paper industry to burn lime and calcium carbonate to produce CaO, which is used again with green liquor to form white liquor.

Kraft - A descriptive term for the (alkaline) surface pulping process, the resulting pulp, and paper or paperboard made therefrom.

Lignin - A non-degradable organic compound of wood which is removed during pulping.

Lime Mud - A solid residue generated from the white liquor clarifier in the lime recovery/white liquor preparation process.

Linerboard - A paperboard made on a fourdrinier or cylinder machine and used as the facing material in the production of corrugated and solid fiber shipping containers.

Market Pulp - A pulp manufactured explicitly for purchase.

Mathieson Process - A process of producing chlorine dioxide, using SO_2 as a reducing agent.

Mechanical Pulp - Pulp produced by physical means without the use of chemicals or heat, often referred to as groundwood.

Metering Rod - A rod used to apply coating to the surface of a sheet, metering even-thickness coating layers on the surface.

Molded Pulp Products - Contoured products, such as egg packaging items, food trays, plates, and bottle protectors, made by depositing fibers from a pulp slurry onto a forming mold of the contour and shape desired in the product.

Mud Filter - A piece of equipment used to thicken and wash lime mud prior to burning it in the lime kiln.

Mud Washer - A piece of equipment used to wash the sodium base chemicals from the lime mud prior to burning it in the lime kiln.

Nip - The point at which two adjacent rolls come together.

Nonwood Fibers - Fibers not of the wood family used to produce pulp, paper, and paperboard. Examples are vegetable fibers (cotton, flax, jute, hemp, cereal straw, bagasse, bamboo, esparto, abaca, sisal, pineapple), animal fiber (wool), mineral fiber (asbestos, glass), and man-made or artifical fiber (rayon, nylon, orlon, dacron).

Nutrients - Elements, or compounds, essential as raw materials for organism growth and development (as in activated sludge process).

Opacity - A measure of the index of transparency of paper, obtained by measuring the quantity of light that is transmitted through the paper sheet.

Oven Dry - A pulp or paper which has been dried to a constant weight at a temperature of 100° to 105°C (212° to 221°F).

Oxidation Pond - A low-rate biological process in which biological treatment takes place in a man-made pond. Dissolved oxygen is supplied by natural aeration processes such as wind, algae, photosynthesis, and partial pressure.

Paperboard - One of the two broad subdivisions of paper products. Paperboard is heavier in basis weight, thicker, and more rigid than paper. In general, all sheets 12 points (0.012") or more in thickness are classified as paperboard. There are a number of exceptions based upon traditional nomenclature. For example, blotting paper, felts, and drawing paper in excess of 12 points are classified as paper while corrugating medium, chipboard, and linerboard less than 12 points are classified as paperboard. Paperboard is made from a wide variety of furnishes on a number of types of machines, principally cylinder and fourdrinier. The broad classes are: 1) container board, which is used for corrugated cartons; 2) boxboard which is further divided into, a) folding boxboard, b) special food board, and c) setup boxboard; and 3) all other special types such as automobile board and building board.

Peroxide - A chemical used in bleaching of wood pulps, usually groundwood pulps.

Porosity - A measure of time required for 100 cc^3 of air to flow through a sample area. Also termed "air resistance" (in seconds per 100 cc^3).

Precipitators - Equipment used to remove ash and other fine solids from gases exiting the boilers and furnaces in a mill.

Precook - Prehydrolysis.

Prehydrolysiss - Pre-steaming of chips in the digester prior to cooking; usually associated with improved bleaching of Kraft pulps.

Press - In a paper machine, a pair of rolls between which the paper web is passed for one of the following reasons: 1) water removal at the wet press; 2) smoothing and leveling of the sheet surface at the smoothing press; and 3) application of surface treatments to the sheet at the size press.

Printability - The ability of a paper surface to accept printing ink.

Pulp - Cellulosic fibers after conversion from wood chips.

Pulper - A mechanical device used to separate fiber bundles in the presence of water prior to papermaking.

Pulping - The operation of reducing a cellulosic raw material, such as pulpwood, rags, straw, and reclaimed paper into a pulp suitable for papermaking.

Pulpwood - Those woods which are suitable for the manufacture of chemical or mechanical wood pulp. The wood may be in the form of logs as they come from the forest or cut into shorter lengths suitable for the chipper or the grinder.

Rag Paper - A paper product manufactured by use of such materials as cotton or linen threads, flax and hemp, raw cotton, and other textile fibers and cotton linters, as well as rags.

Recovery Furnace or Recovery Boiler - A boiler which burns the strong black liquor.

Red Stock - Sulfite pulp after the pulping process, prior to other treatments, such as bleaching.

Reel - 1) A term applied to the untrimmed roll of paper of full machine width wound on a large shaft at the dry end of the paper machine. 2) The shaft on which the paper is first wound when it leaves the driers. 3) A term for the operation of winding paper into a reel.

Refiner - A machine used to rub, macerate, bruise, and cut fibrous material, usually cellulose, in water suspension to convert the raw fiber into a form suitable for formation into a web of desired characteristics on a paper machine. See also Deflaker, and Disk Refiner.

Refining - A general term applied to several operations, all of which involve the mechanical treatment of pulp in a water suspension to develop the necessary papermaking properties of the fibers and to cut the fibers to the desired length distribution. See Refiner.

Rejects - Material unsuitable for pulp or papermaking which has been separated in the manufacturing process.

Repulping - The operation of rewetting and fiberizing pulp or paper for subsequent sheet formation. See also Pulper.

Resin - A special additive used to produce wet-strength in paper or board.

Resin Acid - A naturally occuring organic compound in wood.

Rewinder - A term often used for the winder in the finishing room, distinguishing it from the winder which follows the slitter at the end of the paper machine.

Rewinding - The operation of winding the paper accumulated on the reel of the paper machine onto a core to give a tightly wound roll suitable for shipping or for use in the finishing or converting department.

Rosin - A brittle yellow or amber-colored natural resin that is obtained from southern pine, (types: gum rosin, wood rosin, and tall-oil rosin). Used in papermaking for internal (beater) sizing of paper.

Roundwood - Logs as received in the woodyard. The logs can be any length and usually have not been debarked.

R-2 Process - A modification of the Mathieson process.

Saltcake Loss - The loss of cooking chemical from the Kraft cycle, primarily at the brown stock washers or screen room.

Saveall - A mechanical device used to recover papermaking fibers and other suspended solids from a wastewater or process stream.

Screening - 1) The operation of passing chips over screens to remove sawdust, slivers, and oversize chips. 2) The operation of passing pulp or paper stock through a screen to reject coarse fibers, slivers, shives, and knots.

Screw Press - A device used to recover spent liquor from cooked chips.

Scrubbers - Equipment for removing noxious gases from the exhaust of certain areas in the mill, such as the bleachery or washers.

Sheet - A term used extensively in the paper industry meaning: 1) A single piece of pulp, paper, or paperboard; 2) the continuous web of paper as it is being manufactured; 3) a general term for a paper or paperboard in any form and in any quantity which, when used with appropriate modifying woods, indicates with varying degrees of specificity, attributes of the product such as quality, class, use, grade, or physical properties (Examples: a bright sheet, a Kraft sheet, a folding boxboard sheet); and 4) to cut paper or paperboard into sheets of desired size from roll or web.

Shive - A bundle of incompletely separated fibers which may appear in the finished sheet as an imperfection.

Size - Any material used in the internal sizing or surface sizing of paper and paperboard. Typical agents are rosin, glue and gelatin, starch, modified celluloses, synthetic resins, latices, and waxes.

Size Press - A unit of a paper machine, usually located between two drier sections, used to apply, meter, and evenly distribute size onto paper.

Sizing - 1) Relates to a property of paper resulting from an alteration of fiber surface characteristics. In terms of internal sizing, it is a measure of the resistance to the penetration of water and various liquids. In terms of surface sizing, it relates to the increase of such properties as water resistance, abrasion resistance, abrasiveness, creasibility, finish, smoothness, surface bonding strength, printability, and the decrease of porosity and surface fuzz. 2) The addition of materials to a papermaking furnish or the application of materials to the surface of paper and paperboard to provide resistance to liquid penetration and, in the case of surface sizing, to affect one or more of the properties listed in 1).

Slaker - A device used to regenerate white liquor in the green liquor recovery process.

Slasher - A saw or set of saws used to cut long logs to desired length.

Slitter - A set of knives used to slit a reel of paper into the desired widths as the reel is rewound.

Sludge - Semi-fluid mixture of fine solid particles with a liquid. May contain fibrous and filler materials, and/or biological solids.

Slurry -A suspension of solid particles in a liquid.

Smelt - The molten inorganic cooking chemicals from the recovery boiler.

Soda Process - The first process for the manufacture of chemical wood pulp. Involves boiling wood in caustic alkali at a high temperature.

Softwood - Coniferous woods, such as pines, spruces, and hemlocks.

Solvay Process - A modification of the Mathieson process.

Spent Cooking Liquor - Cooking liquor after digestion containing lignaceous, as well as chemical, materials.

Stock - 1) Pulp which has been beaten and refined, treated with sizing, color, filler, etc. and which, after dilution, is ready to be formed into a sheet of paper. 2) Wet pulp of any type at any stage in the manufacturing process. 3) Paper in inventory or in storage. 4) Paper or other material to be printed, especially the paper for a particular piece of work. 5) A term used to describe a paper suitable for an indicated use, such as coating raw stock, milk carton stock, tag stock, and towel stock.

Stock Preparation - A term for the several operations which ocur between pulping (or bleaching) and formation of the web on a paper machine. It may include, for example, repulping, beating, refining, and cleaning.

Stone - See Grindstone.

Sulfidity - A measure of the amount of sulfur in Kraft cooking liquor. It is the percentage ratio of NaS, expressed as NaO, to active alkali.

Thickener - A device using vacuum or gravity type suction mesh screen to remove excess water from pulp.

Unbleached - A term applied to paper or pulp which has not been treated with bleaching agents.

Vegetable Parchment - A wet strength paper product used as wrapping for moist materials.

Viscosity - The resistance to flow in a liquid; a measurement used in stock preparation as an indicator of pulp condition.

Washer - A piece of equipment, usually either a decker or side hill screen type, equipped with showers to wash chemicals from pulp stock or reject solids.

Wastepaper - A general term used to specify various recognized grades such as No. 1 news, new Kraft corrugated cuttings, old corrugated containers, manila tabulating cards, coated soft white shavings, etc., which are used as a principal ingredient in the manufacture of certain types of paperboard, particularly boxboard, made on cylinder machines where the lower grades may go into filler stock and the higher grades into one or both liners.

Web - The sheet of paper coming from the paper machine in its full width or from a roll of paper in any converting operation.

Wet End - That portion of the paper machine between the headbox and the drier section. See Fourdrinier Machine.

Wet Lap Machine - A machine used to form pulp into thick rough sheets sufficiently dry to permit handling and folding into bundles (laps) convenient for storage or transportation.

Wet Press - The dewatering unit used on a paper machine between the sheet-forming equipment and the drier section.

Wet Strength - The strength of paper after complete saturation with water.

Wet Strength Additives - Chemicals such as urea and melanine formaldehydes used in papermaking to impart strength to papers used in wet applications.

White Liquor - The name applied to liquor made by causticizing green liquor.

White Water - A general term for all papermill waters which have been separated from the stock or pulp suspension, either on the paper machine or accessory equipment, such as thickeners, washers, and savealls, and also from pulp grinders.

Winder - The machine which winds into rolls, the paper coming from the paper machine reel.

Wire - An endless moving belt made of metal or plastic, resembling a window screen, upon which a sheet of paper is formed on a fourdrinier machine.

Wire Pit - A pit under the wire of a fourdrinier machine, which receives some of the water drained or pulled out of the paper sheet.

Wood Flour - Finely ground wood or fine sawdust used chiefly as a filler.

Wood Preparation - A series of operations utilized to prepare wood to a suitable state for further development into pulp, paper, and paperboard. These operations include barking, washing, and chipping.

Woodroom - The area of a pulp mill that handles the barking, washing, chipping or grinding of logs, and processing of purchased chips.

Woodyard - The area of a mill where roundwood is received and stored prior to transport to the woodroom.

Yankee Machine - A paper machine using one large steam-heated drying cylinder for drying the sheet, instead of many smaller ones. Commonly used for manufacturing tissue.

Yield - In pulp and papermaking, the ratio of product to raw material.

Source: U.S. Environmental Protection Agency, "Development Document for Proposed Effluent Limitations Guidelines and Standards for the Pulp, Paper, and Paperboard and the Builders Paper and Board Mills Point Source Categories," U.S. Government Printing Office, Washington, D.C., 1981.

Appendix B

LEGEND OF ABBREVIATIONS

bgd: billion gallons per day

BCT: Paperboard, Course, and Tissue Bleached Kraft

BOD_5: Biochemical Oxygen Demand (five day)

cc: cubic centimeter

EPA: U.S. Environmental Protection Agency

GEMS: General Energy and Material Balance System

gpt: gallons per ton

lb: pound

mgd: million gallons per day

m ton/hr: metric tons per day

NCASI: National Council for Air and Stream Improvement

ppm: parts per million

SIC: Standard Industrial Classification

TDS: Total Dissolved Solids

tpd: tons per day

TSS: Total Suspended Solids

Appendix C

AN OVERVIEW OF THE GEMS COMPUTER SIMULATION PROGRAM

INTRODUCTION

GEMS is a modular computer software system developed for application in the pulp and paper industry by Dr. Lou Edwards at the University of Idaho. Released for commercial license in May 1977, GEMS is the most widely used computer simulation model in the pulp and paper industry. The software consists of an executive program which directs a set of subroutines, or "blocks", which perform individual flow manipulations, i.e., represent mill equipment. Among other functions, the executive program is responsible for calling the proper block in sequence and carrying out calculations in an orderly, iterative manner. The user is responsible for connecting each block in a manner representative of the process in question, along with providing the necessary process data to the executive program.

Three GEMS user manuals are available through Dr. Edwards at the University of Idaho. These three are:

1. GEMS Documentation Describing Data Input, Simulation Control and Simulation Options[1]

2. GEMS Documentation Describing Process Subroutines[2]

3. GEMS Detailed Simulation Examples.[3]

All are essential in familiarization with the GEMS system.

The first manual describes the basic mechanics of constructing the input namelist file. It proceeds line by line through the entire input structure. The second manual outlines the capabilities and data necessary for the proper execution of each GEMS process block. The third manual is useful only after study of the first two. Actual simulations of various parts of the paper-making process are discussed in it. All three manuals are well written and oriented for the user with limited experience in modular process simulation.

While possessing unique capabilities and characteristics, GEMS descends directly from similar software systems developed in the chemical industry. The most significant of these is the FLOWTRAN simulator introduced by the Monsanto Company in 1966[4]. Still in wide use, FLOWTRAN is more sophisticated than GEMS. The former is capable of modeling the thermodynamic behavior of complex chemical mixtures, through the Redlich-Kwong equation of state, and possesses an extensive thermodynamic data bank for individual chemical species. Except for steam data, no such information, nor predictive capability, exists in GEMS. FLOWTRAN is also capable of capital cost estimation. Again, no such capability exists in the GEMS system.

The major advantage of GEMS is the direct applicability of its subroutines to the pulp and paper formation processes. Blocks exist specifically for modeling digesters, deckers, lime kilns, and other equipment used in pulping and paper formation processes. Although GEMS will not predict the complex chemistry at certain points in the pulping process, this is rarely necessary as most data concerning these operations is well documented.

While FLOWTRAN, and its more sophisticated descendant ASPEN (developed at the Massachusetts Institute of Technology), can model a much wider range of chemical flow processes, it is the specificity of GEMS that makes it preferable for use in the pulp and paper industry.

As indicated above, GEMS is an excellent tool for its range of capability. As a steady state material and energy balance simulator, its results center on chemical flow, composition, temperature, and energy requirements for various mill processes. Indeed this was the purpose for which GEMS was designed. As long as this design purpose is kept in mind, GEMS will produce useful information to "what if" process design questions.

CODING

The level of data needed to accurately model a paper process depends on the operation being simulated and the type of output desired. The capability exists in GEMS to track up to 14 separate stream characteristics. The amount of data needed to do so is portional to the number of stream variables tracked. Since in all simulations the gross flows, wood compositions, and stream temperatures are calculated, all data relating to any manipulation of these characteristics are necessary. If further stream variables are tracked, then any parameter relating to the given variable must also be given.

A typical example is the pulp yield loss at digestion. The yield of wood fibers must be known (or assumed) along with data concerning which variable(s) is changed as a result of reactions during the wood cooking process. Parameters relating to hydroxide composition and all recausticizing chemicals, among others, must be known if a more detailed chemical analysis is desired. A more complete description of the data necessary for each block is given in the "GEMS Documentation Describing Process Subroutines" noted earlier.

Input Format

The bulk of a GEMS input file is composed of the block and stream statements, to be described later. Additionally, control statements and descriptive headings must be added before submission. The input data file may be broken into nine basic statements which are described below:

1. Title
2. Execution Control
3. Simulation Size
4. Stream Vector Definition
5. Block Statements
6. Stream Statements
7. Stream Variable Headings
8. Calculation Order
9. Other Options

Each is described in detail below.

1. Title - A title no longer than 72 characters must be inserted at the beginning of each input file.

2. Execution Control - This line contains the data used for controlling the simulation. Such items as the maximum number of iterations, format of output, various input format options, and convergence criteria are specified. Among the more interesting options are the use of convergence acceleration techniques through the bounded Wegstein numerical method and the option of running a dynamic simulation for a transient process. Options are selected by keywords followed by numerical flags. Default values exist for all options; hence the user could simply select nothing and permit the system to control execution.

Example:
&CONTROL LOOPS=100,DELS=0.001,&END

A maximum of 100 iterations is permitted before execution is halted, and convergence will not be achieved until each steam variable deviates from iteration to iteration by no more than 0.1%.

3. Simulation Size - The "EQPMAX" line defines the length of the simulation. Such parameters as the number of blocks in the simulation, the number of streams, and the number of streams whose elements have been pre-defined are given here. An option also exists for the creation of blocks by the user, with the new block names indicated.

Example:
&EQPMAX NEB=3,NSN=3,&END

There are three blocks in the simulation with ten streams, three of which have specified variables.

4. Stream Vector Definition - As mentioned earlier, the number of stream variables tracked may be specified by the user. This selection is made via three index pointers denoting the position of both the suspended solids and the dissolved chemical components. Code names specifying the individual chemicals to be tracked are also indicated.

Example:
&DATA II=4,JJ=4,KK=5,INA=4,ICL=5,&END

In addition to the three default variables tracked (i.e., flow rate, wood composition, temperature), two dissolved components are also tracked, sodium and chlorides, which will be printed as the fourth and fifth variables respectively. The use of the "KK" pointer should be noted, as its value represents the position of the last dissolved component. II and JJ indicate the position of the first and last suspended components, which in this case are not to be tracked.

5. Block Statements - Block statements follow the four control statements listed above, and must be listed in ascending numerical sequence, starting with block 1. Of the approximately 40 different equipment blocks available in GEMS, most can be directly associated with a piece of mill equipment (e.g., WASH, REACT, STMIX, etc.). Blocks are also used for purposes not thought of as requiring machinery, i.e., mixing of two streams (MIXER), or dilution of stock (DILUTE). In short, any manipulation of a process variable requires the insertion of an equipment block.

Blocks typically have a general function which is broken into several subfunctions, or options. For example, one block exists whose function is to split a process stream vector into two portions. Obviously, there are many criteria under which a stream may be split: set stream consistency, set flow rate, set chemical composition, or obtain an arbitrary fraction of the input stream. The block option, along with data relating thereto, must be indicated before execution can begin.

While blocks are consecutively numbered, calculation proceeds from block to block in the order specified by a GEMS control statement. The streams to be manipulated must be specified for each block. Input streams are indicated as positive and precede the output streams which are negative.

Block coding can best be illustrated through an example; two options of the SPLIT block are presented.

```
1.   &P NE=4,NAME=SPLIT,KP=3,-4,-5,EQP=1,0,350,&END
2.   &P NE=4,NAME=SPLIT,KP=3,-4,-5,EQP=3,0.05,0,0.5,&END
```

Both statements are identical except for the option specified, and hence the data required. The "&P" and "&END" strings denote the beginning and end of a block statement respectively. Input and resultant streams are laced after the "KP" string, while the parameters relating to the block's mode of operation follow the "EQP" string. Both statements are for block 4 (denoted by the 4 after the NE string), which is a SPLIT BLOCK (denoted after the "NAME" string), with stream 3 entering and stream 4 and 5 exiting. The order of stream specification for a SPLIT block is significant in that data presented apply to the first exiting stream, in this case stream 4.

In case 1, stream 4 is to be set to a specified flow rate of 350 metric tons per hours. The block option is set by the first argument after the "EQP" string, the flow rate by the third argument. The order of arguments is completely dependent upon the block and option considered and is exactly analogous to a FORTRAN call statement.

In case 2, stream 4 is to be set to a consistency of 0.05, indicated by arguments 1 and 4 respectively. It should be noted that when an argument is not used in a particular option, it is either given a value of 0 or omitted if it falls after the last argument in the option considered.

6. Stream Statements - Stream statements follow the block statements and may be listed in a random fashion. The bulk of GEMS output is related to the characteristics of process streams. Indeed, the purpose of a GEMS block is to mathematically model stream manipulations. Streams in GEMS may be conceptualized as vectors of dimension represented by the number of characteristics tracked. Vector length is limited to 14 elements, the first three of which are stream flow, stock content, and temperature. The other eleven variables are divided into two categories: suspended solids and dissolved chemical components. The first group is used to track individual fractions of the stock flow (e.g., knots fines, etc.). The second group is used to track various dissolved chemical groups such as sodium, hydroxides, sulfides, dissolved wood, carbonates, sulfates, and chlorides. Options exist to track other user specified components.

Stream vectors are numbered, not necessarily sequentially, up to 300. Only the variables for the streams input to the process must be defined. All internal streams are defined through calculation. This feature is particularly conducive to the calculation of recycle streams which in many cases may only be defined through an iterative process. Stream variables are specified by the following statement format: &SNS=3,STV=100,0.05,50,&END

The "&S" and "&END" strings denote the beginning and end of a stream statement respectively. The liquor in stream 3 flows at a rate of 100 metric tons per hour, has a stock compositon of 0.05 tons per ton of liquor, with a temperature of 50^{o}C. Other stream variables, if tracked, would be listed after the temperature. Order of stream variable input other than the three seen above is governed by a user specified GEMS control statement.

7. Stream Variable Headings - Following the stream statements, each stream variable must be given a name of up to 15 characters to aid in reading results. The content of each string is purely arbitrary, although each should indicate the content of the stream variable it will denote as output.

8. Calculation Order - The last line in a GEMS input simulation (provided there are no MACROs or alternative executions) specifies the order in which each block is called, along with the mode of calculation for each block. Calculation order refers to the sequence a particular string of blocks is called, i.e., a process of three blocks may be calculated in the order 1,2,3, or 2,1,3, etc., depending

on the content of the CORDER command. The user may choose the mode of calculation of a block through the NEMODE option. Three modes may be chosen:

- o In mode 1, the block is calculated directly with no additional iteration.
- o In mode 2 (the default value), the block is calculated as in in iterative loop.
- o In mode 3, the block is calculated as at the end of an iterative loop.

These options are designed to allow the user to direct operation so as to minimize computer execution time. Decisions concerning the exact manner to use them are generally esoteric in nature. It is important to note that there is no default order specification in the CORDER command. Some kind of permutation must be specified with each block in the process listed or an error message will result.

Example:
&CORDER NECALL (1)=1,2,3,NEMODE(1)=2,2,2,&END

A process of three blocks is called in ascending numerical sequence, with each block calculated as in an iterative loop.

9. <u>Other Options</u> - In addition to the standard format described above, GEMS has two major execution options that may be utilized:

- o The ability to make changes in equipment and stream parameters from run to run in a single job;
- o The capacity to combine groups of GEMS blocks into one single, large block or "MACRO".

Both of these options require additional coding appended to the standard GEMS input format.

In utilizing the multiple run capacity, changes in parameters may be varied to examine their effect on the process. This option is especially helpful in identifying process trends such as dissolved solids concentration at varying water usage levels. Input required is only that needed to indicate which streams and parameters are to be changed.

The MACRO option is extremely useful in that an entire mill process may be added or deleted by the manipulation of a single block rather than a complex set of linked flows. In a sense, it further modularizes the process. A name is given to the MACRO block, and its streams are cross-referenced to the MACRO coding found at the end of the GEMS datafile. Only the MACRO streams interacting with the general process need be cross-referenced; the internal MACRO streams are calculated separately.

Output Format

GEMS output is almost completely self-explanatory after the user has constructed an input file. The general structure is as follows:

1. Input data

2. History of calculation

3. Results of calculation

A brief description of each item follows.

1. Input Data - This section of the output file is printed to give the user a more readable form of the input data. All input data are reprinted, including the default options assigned by the system. All data relating to convergence criteria, process sequence, stream variables tracked, and stream vectors specified are printed. Syntax errors in the input file will also be denoted.

2. Calculation History - This section of output allows the user to find points of sluggish convergence within the process. Although generally not useful if convergence is achieved, the error citations for each block can be invaluable in error analysis. The nature of the errors for each block is given (e.g., insufficient liquor for a given stream split specification, stream temperature in excess of specified output temperature for a heating block, etc.) to allow proper manipulation of input data by the user.

3. Calculation Results - The results of execution are printed under two headings: block parameter results and stream variable calculations. Input data for each of these two items (i.e., the stream variables specified, along with the equipment parameters) are reprinted. Most blocks do not contain any computed output, and thus the input data are simply reprinted. Those that do contain computed output include STMIX (e.g., steam consumption, output temperature), and PUMP (e.g., brake housepower required). By far the greatest source of output information consists of the stream variable data. This section contains all data relating to internal stream flows and compositions as specified by the user. Output is printed in columns under the descriptive headings specified as input.

SAMPLE CALCULATION

The following example should illustrate this procedure.

Under current mill operations, fresh water heated to 60°C is used to wash the spent cooking chemicals from the brown stock. It is proposed to decrease fresh water intake by using dilution overflow for wash displacement water, in the belief that steam consumption will drop significantly from the present level (69.1 tons per hour of 50 psig steam used to heat the wash water). A constraint upon process water quality leaving dilution is a dissolved solids level no greater than 3500 ppm. Given this constraint, is the proposed reroute possible? If so, what is the possible steam savings in tons consumed per hour? A process diagram and complimentary GEMS block diagram are seen in Figures C-1 and C-2. The following data apply to the process in question.

Process Data

Stock in:	500 mton/hr 20% consistency 75°C 5000 ppm dissolved solids
Fresh water:	1000 mton/hr 25°C 10 ppm dissolved solids
White water:	5000 mton/hr .005 consistency 2700 ppm dissolved solids
Decker:	Efficiency factor = 1.5 Output consistency of stock = 0.13
Screen:	0.5% of incoming pulp is rejected at incoming consistency (13%)
Dilution:	Brown stock diluted to 3% consistency
Steaming:	Indirect, temp of wash water increased to 60°C Steam quality: 50 psig, saturated

Results

The proposed process modification required a change in only one equipment block stream label: the STMIX block fresh water input stream was changed from stream 9 to stream 6, the dilution overflow whitewater stream (Figure C-3, line 8). It should be noted that the cool 25°C, relatively clear fresh water stream is being replaced with a 50°C stream of higher dissolved solids content. In the original case, the existing stock stream (stream 7) had a dissolved solids content of 2240 ppm (2.240 kg. per metric ton of liquor). The same stream after the proposed reroute was imposed had a solids level of 2844 ppm, well under the 3500 ppm operational constraint (Figure C-4, line 183). The amount of steam conserved is impressive. As previously mentioned, the original flow pattern required a steam consumption of 69.1 tons per hour of 50 psig steam to heat the incoming wash water, whereas after the new proposal was implemented steam consumption dropped to 20.5 tons per hour (Figure C-4, line 170), a savings of 70.3%.

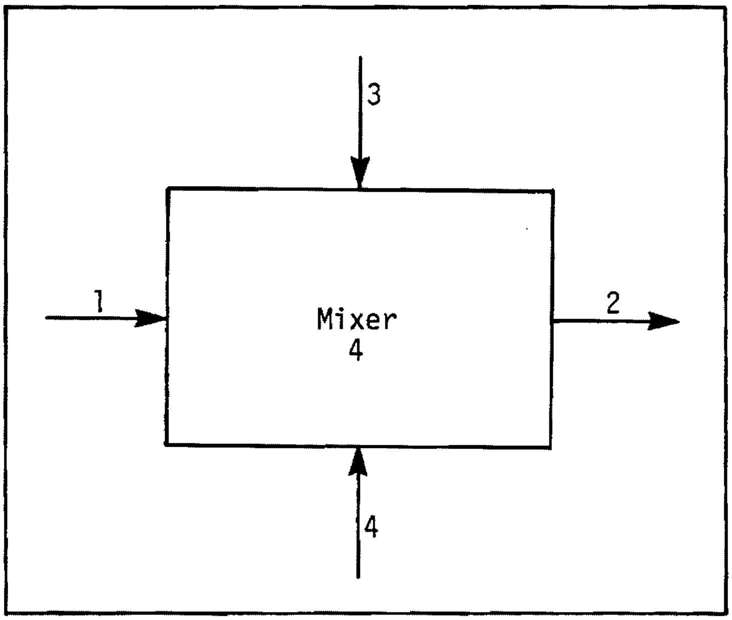


Figure C-1. SCHEMATIC OF MIXER BLOCK

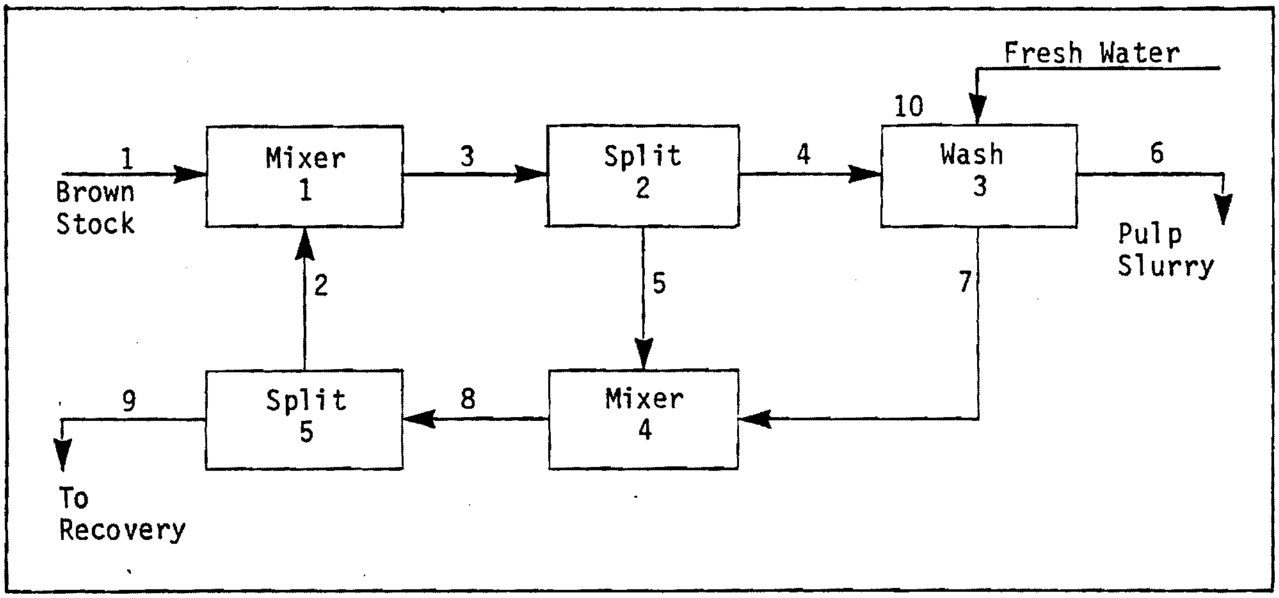


Figure C-2. GEMS SCHEMATIC FOR DRUM WASHING

```
SAMPLE EXECUTION
$CONTRL LOOPS=2000,$END
$EQPMAX NEB=4,NSN=10,NSVS=3,$END
$DATA KK=4,$END
$P NE=1,NAME=WASH,KP(1)=1,10,-3,-2,EQP(1)=1.5,0.13,0.,$END
$P NE=2,NAME=SPLIT,KP(1)=3,-4,-5,EQP(1)=3,0.13,0.,0.005,$END
$P NE=3,NAME=DILUTE,KP(1)=5,8,-7,-6,EQP(2)=0.03,$END
$P NE=4,NAME=STMIX,KP(1)=6,-10,EQP(1)=4.0,0.,0.,60.,3346,$END
$S NS=1,STV(1)=500,0.25,75.0,5.00,$END
$S NS=8,STV(1)=5000,0.005,50.,2.70,$END
$S NS=9,STV(1)=1000,0.00,25.0,0.01,$END
LIQUOR(MTON/HR)
PULP(TN/TN LIQ)
TEMP(C)
DIS SOL (KG/TN)
$CORDER NECALL(1)=1,2,3,4,NEMODE(4)=3,$END
16
```

Figure C-3. SAMPLE EXECUTION INPUT FILE

```
                          GEMS

         GENERAL ENERGY AND MATERIAL BALANCE SYSTEM


                 A MODULAR COMPUTER SYSTEM
               FOR PULP AND PAPER APPLICATIONS

                    RELEASE: MAY, 1977


                       LOU EDWARDS

                        RON BALDUS




            DEPARTMENT OF CHEMICAL ENGINEERING,

                   UNIVERSITY OF IDAHO

                      MOSCOW, IDAHO





          THREE GEMS MANUALS ARE AVAILABLE AT COST


          1. DOCUMENTATION DESCRIBING DATA INPUT,
             SIMULATION CONTROL AND SIMULATION OPTIONS

          2. DOCUMENTATION DESCRIBING PROCESS SUBROUTINES

          3. DETAILED SIMULATION EXAMPLES
      GENERAL ENERGY AND MATERIAL SIMULATOR PROGRAM

          150 EQUIPMENT BLOCKS
            6 STREAMS TO AND FROM A BLOCK
           10 EQUIPMENT PARAMETERS PER BLOCK
          300 STREAMS
           14 STREAM VARIABLES

      SAMPLE EXECUTION

      READ DATA SET :  CONTRL

      DYNA=0         FACT1= -150.  FACT2=     0.  IAUTO=1        IBUG=     0
      IFPR=0         IREAD= 1      ITSTRT=10000  KOP=11         KPORT= 0
      LOOPS=2000     MACRO= 0      MAXERR= 50    MODZ= 0        NFILE= 0
      NPRINT=10000
```

Figure C-4. SAMPLE EXECUTION OUTPUT FILE

```
 STREAM VARIABLES

                LIQUOR(MTON/HR)   PULP(TN/TN LIQ)   TEMP(C)          DIS SOL (KG/TN)

         1        500.0000          .2500000         75.00000          5.000000
         8        5000.000          .5000000E-02     50.00000          2.700000
         9        1000.000         0.                25.00000          .1000000E-01


         DATA INPUT WITH     0 ERRORS

         SUCCESSFUL DATA ENTRY :  PROCEED WITH EXECUTION

         BEGIN ENERGY AND MATERIAL BALANCES


         BEGIN ITERATION WITH THE FOLLOWING BLOCKS:
              1,  2,  3,  4,

 ERRORS FOR ITERATION    1 ARE :     12401


         CONVERGENCE IN     7 ITERATIONS

         GEMS PROCESS SIMULATION RESULTS

 EQUIPMENT PARAMETERS

 NAME      NO.    PARAMETERS

 WASH       1      1.50000         .130000        0.             0.            0.
                  0.             0.             0.             .651562       1.19134

 SPLIT      2      3.00000         .130000        0.             .500000E-02   0.
                  0.             0.             0.             0.            0.

 DILUTE     3     0.              .300000E-01    0.             0.            0.
                  0.             0.             0.             0.            0.

 STMIX      4      4.00000       0.             0.             60.0000       3346.00
                  0.             0.             0.             20.4890       10379.5


 STREAM VARIABLES

                LIQUOR(MTON/HR)   PULP(TN/TN LIQ)   TEMP(C)          DIS SOL (KG/TN)

         1        500.0000          .2500000         75.00000          5.000000
         2        666.7102         0.                65.03621          3.377590
         3        871.2709          .1494253         65.22658          3.501408
         4        4.356355          .1494253         65.22658          3.501408
         5        866.9146          .1494253         65.22658          3.501408
         6        1037.958          .5000000E-02     50.00000          2.700000
         7        4828.956          .3092784E-01     52.84474          2.843872
         8        5000.000          .5000000E-02     50.00000          2.700000
         9        1000.000         0.                25.00000          .1000000E-01
        10        1037.958          .5000000E-02     60.00000          2.700000
```

Figure C-4. SAMPLE EXECUTION OUTPUT FILE (cont'd)

```
CONVERGENCE CRITERIA

      VARIABLE      DEL    VARIABLE     DEL
          1        .0010      8        .0010
          2        .0010      9        .0010
          3        .0010     10        .0010
          4        .0010     11        .0010
          5        .0010     12        .0010
          6        .0010     13        .0010
          7        .0010     14        .0010

READ DATA SET :  EQPMAX

PROCESS CONSISTS OF :   4 EQUIPMENT BLOCKS
                       10 STREAMS
                        3 STREAMS WITH SPECIFIED VARIABLES

EQUIPMENT BLOCKS AVAILABLE :  NUMBER AND NAME

          1  REACT          2  MIXER          3  SPLIT
          4  HEATX          5  STMIX          6  CTRL
          7  EVAPS          8  KFURN          9  SLAC
         10  KILN          11  MGSFURN       12  LTV
         13  DILUTE        14  WZONE         15  TURB
         16  GREC          17  VRC           18  SCTRL
         19  SDT           20  CFST          21  PLUGF
         22  SALTRM        23  CHARGE        24  WASH
         25  FLASH         26  EECTRL        27  EDCTRL
         28  HEADER        29  PDROP         30  PBOIL
         31  HREC          32  CND           33  DESUP
         34  GCTRL         35  PUMP          36

READ DATA SET :  DATA

JJ= 4         KK= 4         NOSORB=0
INA=15        IOH=15        IDIS=15       IS2=15        IS04=15
ICL=15        IC03=15

READ PROCES INFORMATION FROM INPUT DATA

READ STREAM INFORMATION FROM INPUT DATA

READ DATA SET :  CORDER


PROCESS MATRIX

NO.     NAME    MODE   CORDER MODE    STREAMS IN AND OUT

 1     WASH      2       1     2      1    10    -3    -2    0    0
 2     SPLIT     2       2     2      3    -4    -5     0    0    0
 3     DILUTE    2       3     2      5     8    -7    -6    0    0
 4     STMIX     3       4     3      6   -10     0     0    0    0

EQUIPMENT PARAMETERS

NAME     NO.    PARAMETERS

WASH      1      1.50000         .130000        0.           0.              0.
                0.              0.              0.           0.              0.

SPLIT     2      3.00000         .130000        0.           .500000E-02     0.
                0.              0.              0.           0.              0.

DILUTE    3     0.               .300000E-01    0.           0.              0.
                0.              0.              0.           0.              0.

STMIX     4      4.00000        0.              0.           60.0000         3346.00
                0.              0.              0.           0.              0.
```

Figure C-4. SAMPLE EXECUTION UOTPUT FILE (cont'd)

References - Appendix C

1. Edwards, Lou, and Ron Baldus. GEMS Documentation Describing Data Input, Simulation Control and Simulation Options. Idaho Research Foundation, Inc., Moscow, ID, 1979.

2. Edwards, Lou, and Ron Baldus. GEMS Documentation Describing Process Subroutines. Idaho Research Foundation, Inc., Moscow, ID, 1979.

3. Edwards, Lou, and Ron Baldus. GEMS Detailed Simulation Examples. Idaho Research Foundation, Inc., Moscow, ID, 1979.

4. Seader J.D., W.D. Seider, and A.C. Pauls. FLOWTRAN Simulation-An Introduction. Computer Aids for Chemical Engineering Education, Cambridge, MA, 1977.

Appendix D

MILL VISITS

INTRODUCTION

In an effort to gain a closer appreciation for factors influencing water recycle/reuse by the pulp and paper industry, 25 mills were visited to augment published technical information concerning fresh water usage practices within the industry. The primary objectives of the survey were to

1. Visit average and below average water consumers in the process subcategories selected.

2. Determine by process system the common or typical reuse/recycle techniques employed.

3. Determine the major limitations to present and future reuse/recycle.

4. Correlate regional relationships for mill freshwater usage practices.

5. Identify those water recycle/reuse projects currently underway.

6. Determine major development areas being employed by mills in selecting capital projects.

MILL SELECTION AND SURVEY METHODOLOGY

Since it was impractical to visit every pulp and paper facility across the U.S., the team sampled mills in the ten major subcategories studied. These mills were selected for one of two reasons:

1. They represented an average or low water consumer in their respective subcategories;

2. They represented a subcategory in a major water consuming region (see Figure D-1).

Several publications, such as the NCASI Technical Bulletins of the 1970's, have quantified specific plant constraints in water reuse/recycle. These works have accumulated a rich resource of data on specific operational criteria which various plants require for satisfactory operation. Information on the limits of pulp fines, calcium carbonate, and corrosives in machine white water systems for example have been tabulated to identify quality requirements for specific mills (and specific pulp/paper types). The audit format for this study was designed not to regenerate or update this data but to

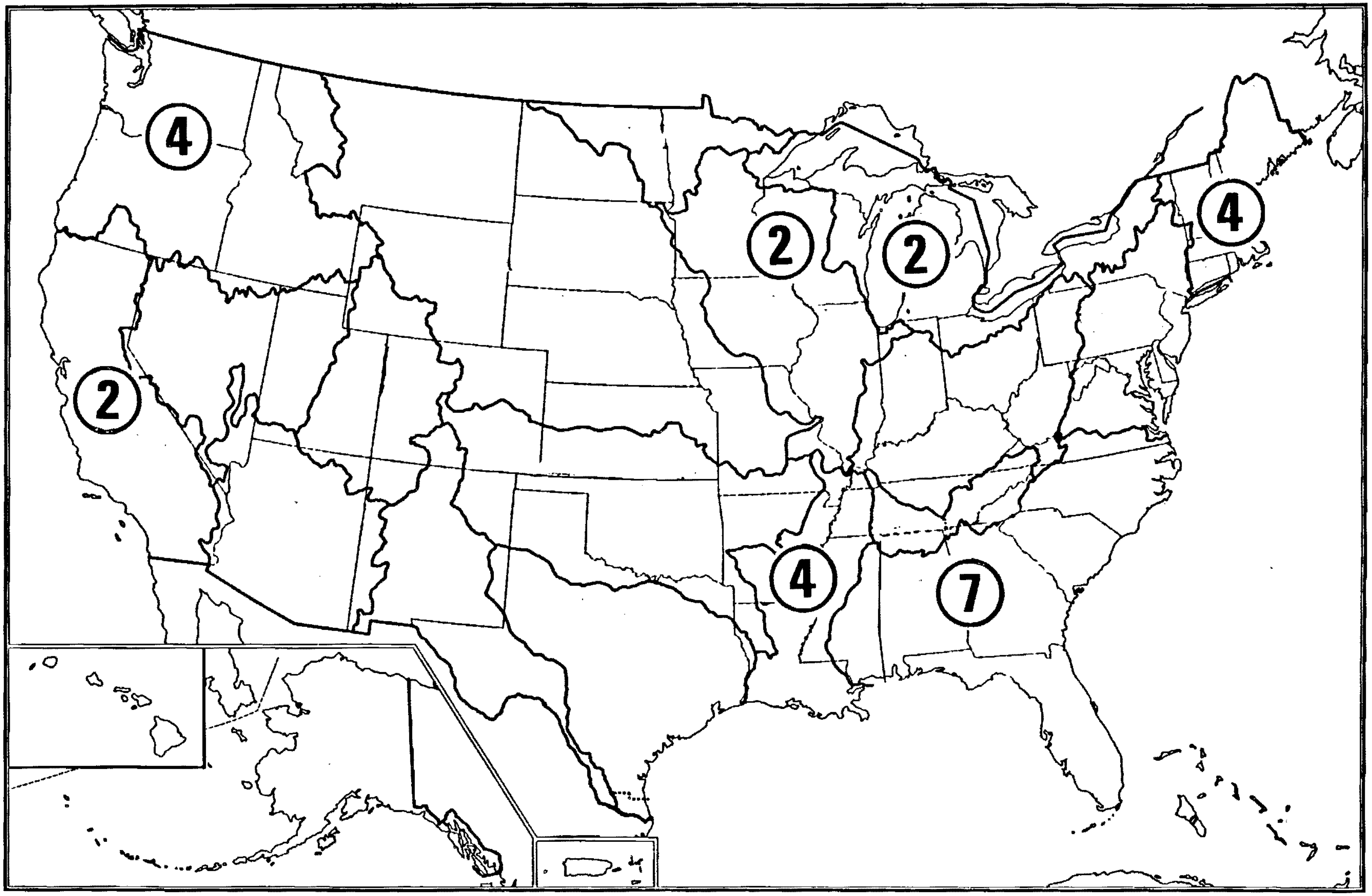


Figure D-1. DISTRIBUTION OF MILLS SURVEYED BY WATER RESOURCE REGION evaluate the qualitative constraints limiting additional reuse/recycle. This information coupled with previous work were then used to identify specific problems facing U.S. mills and to determine the magnitude of those problems.

The mill survey was divided into two basic sections. The first section, entitled Fundamental Mill Data, requested basic numerical process information required to make modeling possible. This information included specific units of input and output, thus setting limitations for the various subprocesses throughout the plant.

The second section, entitled Survey Questions - Production and Process Controls, contained questions designed to acquire specific internal mill process information on primary material flow routes. These questions were both qualitative and quantitative in that they facilitated the development of a basic water balance within the mill departments. This section also yielded the anticipated restrictions of further water reuse and identified planned activities and external forces which may modify current mill operations and water usage practices. At the end of this Appendix is a copy of the survey questions.

Survey Results

Table B-1 shows water usage values for the mills visited. Many of the mills visited gave similar results in terms of recycle schemes, regional constraints, and current motivations for increased recycle, but it is interesting to note that almost every mill offered unique technical data. These technical bits offered qualitative highlights to the visit and reflected the general attitude of the mill toward recycle/reuse. Below is a list of the more prominent examples - each followed by a letter designation which correlates to a specific mill(s) in Table D-1.

- Major problem with water reuse on machine is fines - shower, wire, and felt pluggage (B)
- Machine close-up is probably justifiable on energy savings alone (B)
- Utilizing chlorination stage filtrate for bleach plant stock input dilution is cost effective as a chemicals savings (and eliminates pitch build-up in unbleached stock lines) (D,N)
- Pitch build-up in machine white water showers may be cleaned by intermittent use of freshwater (F)
- Due to acid cooking in papergrade sulfite process, pitch build-up on machine (and other dissolved solids) is a significant limiter of machine white water reuse (H)
- Spent sulfilte liquor is a good source of wood sugars for ethyl alcohol (H)

Table D-1. CURRENT FRESH WATER USAGE RATES OF MILLS VISITED

Mill	Total Water Usage (million gal/day)	Mill Prod. Rate (tons/day)	Water Usage (1000 gals/ton)	Category Ave. (1000 gal/ton)	Mill Category (type)
A	15	1800	8.3	15.8	Unbleached Kraft
B	6	1400	4.2	15.8	Unbleached Kraft & Wastepaper
C	56	1700	32.9	35.0	Market Bleached Kraft
D	20	600	33.0	35.0	Market Bleached Kraft
E	20	600	36.4	37.6	BCT Bleached Kraft
F	27.3	1000	27.9	35.0	Market Bleached Kraft
H	30		35.1	51.4	Papergrade Sulfite
I	4.8	160	30	51.4	Papergrade Sulfite
K	3	300	10	51.4	Papergrade Sulfite
L	25.9	875	29.5	35.0	Market Bleached Kraft
M	1.9	150	12.7	18.4	Nonintegrated Fine Paper
N	20	875	22.9	44.9	Alkaline Fine
O	12	350	34.3	44.9	Alkaline Fine
P	26	850	30.6	37.6	BCT Bleached Kraft
Q	12	1050	11.4	11.4	Unbleached Kraft/Semi-Chem.
R	30	1200	25	37.6	Bleached Kraft
*S	2.1	330	6.4	18.4	Nonintegrated Fine Paper
*T	3	315	10.0	18.4	Nonintegrated
V	14	1356	10.4	15.8	Unbleached Kraft & Semi Chem.
W	40	2110	18.9	15.8	Unbleached Kraft & Miscellaneous
X	30	1285	23.3	35.0	Market Bleached Kraft
Y	33.6	775	43.4	44.9	Alkaline Fine
Z	30	1014	29.6	44.9	Alkaline Fine
AA	55	1200	45.8	44.2	Dissolving Kraft

*Mills not in our specific process categories of study but are of interest due to low water usage rates

- o Unsteady state mill operation may account for more than 10% of water consumption (J)
- o Reverse osmosis for water reuse/recycle treatment is unreliable at present for commercial applications (J)
- o More efficient water reuse is possible by obtaining mill water from different sources. For example: Boiler feedwater may come from well water or municipal systems while less demanding applications may utilize river water or even municipal waste water (K,S,T,B)
- o 1500 gal/ton of water may be consumed for seal water in pumps, (L) agitators, bearing cooling, etc.
- o Pitch build-up may be attributed to waste pulp reuse (L)
- o Water reuse/recycle is a major factor in meeting effluent permits when waste treatment system is of limited capacity (O)
- o Bleach plant close-up is justifiable on thermal energy savings (P)
- o Economics may favor a small sulfite pulping process in conjunction with large Kraft mills for increased water reuse/recycle efficiency and for Kraft liquor system chemical savings (Q)
- o Plant waste heat may be used for greenhouses or fish hatchery (R)
- o Mechanical pump seals offer better service now than in the past (S)
- o Tertiary treated municipal waste water is an acceptable source for many mill processes (T)
- o Computer management of mill processes offers significant promise in controlling process losses, and therefore fresh-water requirements, during both steady state and interrupted operations (U)

It is interesting that many mills with similiar processes and products had widely varying approaches to water reuse/recyle. Outwardly it appeared that a cost effective system arrangement for one mill would be attractive to another. The most notable example of this concept is in the utilization of evaporator clean condensates. Most mills did not find this source of water suitable for reuse as boiler feedwater. Because of a history of contamination or an occasional upset, the majority of mills applied this wastewater stream to the pulping area for brown stock washing. Yet, some mills controlled processes well enough for this high quality source of water to be used satisfactorily as feedwater makeup or even shower water on the paper machine.

Quantitative information needed for computer modeling was not always available from the mills. This was generally a product of deficient internal process metering and an issue of a mill's willingness to provide such information. The unbleached Kraft mills were particularly prone to not knowing water flows in many of their specific processes and subprocesses. Participants sometimes offered design conditions according to mill blueprints, but admitted that these blueprints are frequently out of date and did not necessarily reflect many of the recent process changes which had taken place.

All of the mills were able to provide reasonably accurate information in most areas of their operation. Missing information was typically found by calculation using what information was known. For example, if total freshwater consumption on the paper machine was not known, but the fourdrinier headbox consistency was known, then a determination of water demand was possible by using the production output of the machine. Modeling with the calculated numbers plus numbers provided by a mill yielded a total mill water consumption that matched closely with total effluent volumes that were known. Organizing the process flows on the GEMS model allowed a check to verify calculated quantities. The final output was then reviewed with plant personnel by telephone to verify if estimations closely matched what they expected. This technique proved effective because unknown quantities were typically few, and enough information from the audits was obtained to satisfactorily verify values that were generated through in-house calculation.

With regard to data being withheld, only in one case did the problem of proprietary information limit the amount of data that was collected in the field visits. However, several mills did not provide cost information regarding fresh water acquisition and treatment. Of these, some simply indicated that they did not have accurate numbers. Lack of this data hindered the review of limitations on increased water recycle/reuse.

There were some difficulties encountered with regard to the recycle rate of mills located in regions of plentiful water supplies with substantial seasonal fluctuation in water temperature. In the warm summer months cooling water volumes for such mills were found to escalate and subsequently led the mill to use the water elsewhere in production operations on a once-through basis. This resulted in a substantial reduction in water reuse during periods of heavy cooling loads. In order to recognize this constraint, winter water reuse figures were used as typical for such mills with a note made that increases in summer usage was common due to heavy cooling loads.

A number of industry concerns and observations were generated by the survey. The single most consistent comment concerning technical constraints in recycle/reuse was the inability of mills to obtain satisfactory shower operations using white water. The primary concern expressed was shower pluggage which immediately affected sheet moisture profiles and led to paper/pulp breaks. As a result of problems many mills had resorted to the use of freshwater in this area to eliminated production/quality problems and possibly filtration equipment maintenance.

All mills were found to employ saveall systems for dilution water to stock preparation even though many were found to be troublesome. From the information obtained from mill spokesmen, the primary problem with white water recycle (predominately for some fourdrinier showers) was not during normal operation but rather during upsets when slugs of fiber were sent into clarified white water streams, blocking filters and/or plugging showers. It was expressed that more complete recycle could be routinely practiced if existing saveall systems were more dependable or were more effective. Clarifier type savealls were found to offer the greatest potential effectiveness in dependability and degree of fiber separation. Unfortunately space constraints frequently limited its applicability to many mills. Only one of the mills visited in the survey utilized a clarifier system (of modified form). Hence, mills are not rushing to implement this dependable design.

Two mills studied indicated that scale or pitch buildup was actually reduced when utilizing white water on showers. The reason behind this was that there was less deviation between process and wire pH, preventing abrupt changes that precipitate scale or pitch. Publications support this and further state that this recycle scheme should reduce wire pit pH control cost and sizing costs. Those mills that utilized extensive recycle cited an increase in machine temperature of roughly 20^{o}F. This increase might pose a problem for those mills that operate in excess of 135^{o}F at present. There is also a correlation between saveall performance (and reliability) and the type of fiber in the process. Long fiber pulps enable conventional drum or disc type savealls to operate more satisfactorily.

Felt conditioning systems were found to be almost universally operated on freshwater due to the pluggage problems associated with high pressure-small orifice showers. Technical developments in purifying white water for this application were found to be quite limited. Thrusts in the direction of very high pressure (500 psig), low volume intermittent freshwater showers, while documented in the literature, were not found to be extensively in use.